DELTA RISK MANAGEMENT STRATEGY

INITIAL TECHNICAL FRAMEWORK PAPER

ENVIRONMENTAL RISK ASSESSMENT

Prepared by:
URS Corporation/Jack R. Benjamin & Associates, Inc.

Prepared for:
Department of Water Resources

September 6, 2006

Environmental Risk Assessment

Charles Hanson (Hansen Environmental, Inc.); Marty McCann (Jack R. Benjamin & Associates, Inc.); Craig Stevens (Stevens Consulting); Jon Rosenfield; Pete Rawlings (Science Application International); Terry Cooke and Alexandra Fraser (URS Corporation); and Kristie Karkanen

Foreword

The purpose of the Delta Risk Management Strategy (DRMS) Initial Technical Framework (ITF) is to guide the analysis of specific technical topics as they relate to assessing potential risks to Delta levees and assets resulting from various potential impacts (e.g., floods, earthquakes, subsidence, and climate change). These ITFs are considered “starting points” for the work that is to proceed on each topic. As the work is developed, improvements or modifications to the methodology presented in this ITF may occur.

The Sacramento–San Joaquin Delta (referred to as the Delta) and Suisun Marsh provide habitat for a diverse estuarine community, including fish, shrimp and crabs, zooplankton, aquatic and terrestrial plants, and wildlife. The estuary ecosystem supports extensive recreational fishing, boating, aesthetic enjoyment, and commercial fisheries. Over the past 150 years a number of factors have influenced the fish and wildlife communities inhabiting the Delta and Suisun Marsh, including loss of access to upstream habitat through construction of dams and impoundments, land use changes, reclamation and channelization/levee construction, exotic species introductions, water diversions and changes in seasonal hydrologic patterns, and other changes. As a result of these and other factors, many of the species have experienced substantial declines in abundance and geographic distribution, leading to the listing of several species under the California and/or Federal Endangered Species Acts and the identification of others as species of special concern.

Levee failures that lead to the flooding of islands within the Delta or Suisun Marsh have the potential both to directly affect these at-risk species and other aquatic and terrestrial species and to indirectly affect them by changing the quality and availability of suitable habitat and altering fundamental estuarine processes.

The purpose of this ITF paper is to describe the approach that will be used to assess the potential environmental effects of levee failures on selected aquatic and terrestrial species. As a result of limitations on available information regarding the response of various species and their lifestages to changes in environmental conditions, the environmental effects analysis will include both quantitative and qualitative measures of impact/benefit. The environmental effects analysis has been designed to evaluate the potential environmental effects on selected species over a wide range of levee failure scenarios at both the individual and regional population level of analysis.

Table of Contents

Tables

Figures

1.0 INTRODUCTION

The Sacramento-San Joaquin Delta (referred to as the Delta) and Suisun Marsh provide habitat for a diverse estuarine community including fish, shrimp and crabs, zooplankton, aquatic and terrestrial plants, and wildlife. The estuary ecosystem supports extensive recreational fishing, boating, aesthetic enjoyment, and commercial fisheries. Over the past 150 years a number of factors have influenced the fish and wildlife communities inhabiting the Delta and Suisun Marsh, including loss of access to upstream habitat through construction of dams and impoundments, land use changes, reclamation and channelization/levee construction, exotic species introductions, water diversions and changes in seasonal hydrologic patterns, and other changes. As a result of these and other factors, many of the species have experienced substantial declines in abundance and geographic distribution, leading to the listing of several species under the California and/or Federal Endangered Species Acts (ESA) and the identification of others as species of special concern.

Levee failures that lead to the flooding of islands within the Delta or Suisun Marsh have the potential to both directly affect these at-risk species and other aquatic and terrestrial species, and to indirectly affect them by changing the quality and availability of suitable habitat and altering fundamental estuarine processes.

The purpose of this Initial Technical Framework (ITF) is to describe the approach that will be used to assess the potential environmental effects of levee failures on selected aquatic and terrestrial species. As a result of limitations on available information regarding the response of various species and their lifestages to changes in environmental conditions, the environmental effects analysis will include both quantitative and qualitative measures of impact/benefit. The environmental effects analysis has been designed to evaluate the potential environmental effects on selected species over a wide range of levee failure scenarios at both the individual and regional population level of analysis.

The sections below outline the basic objectives of the environmental effects analysis, and describe the evaluation process, identify information that will be needed to conduct the analysis, list anticipated outputs and products, describe the series of tasks required to complete the analysis, and present the schedule for completing the environmental effects analysis.

2.0 OBJECTIVES

The primary objective of the environmental effects analysis is to assess the potential environmental impacts/benefits to aquatic, plant, and wildlife species within the Delta and Suisun Marsh in response to (and conditional on) levee failures that may be initiated by floods, seismic events, wind-wave action, or normal events (e.g., seepage, animal burrowing). These levee failures could range from single levee breaches to catastrophic events involving multiple breaches affecting a number of islands within the Delta and Suisun Marsh. The environmental effects analysis has been designed to capture and describe the affects on a range of scales from effects on individuals within the population and the potential risk of population-level changes.

As part of the analysis, both the aleatory and epistemic sources of uncertainty in the species response to levee failures and the associated changes in habitat conditions will be evaluated (see Section 4 for a discussion of these types of uncertainty). The results of this analysis will be used in the overall Delta risk model to assess the potential magnitude and significance of adverse impacts/environmental benefits of levee failure to selected aquatic and terrestrial species currently inhabiting the estuary.

3.0 STATE OF KNOWLEDGE REGARDING THE DELTA/SUISUN MARSH AQUATIC AND TERRESTRIAL COMMUNITIES

The Delta and Suisun Marsh is a complex estuarine ecosystem that is a transition zone between inland sources of freshwater and saltwater from the ocean. Human intervention in the system has caused a decrease in the deposition of mineral sediments in this area (e.g., due to blockage of sediments by upstream dams) and an increase in the rate of decomposition (oxidation) in the organic soils from agricultural activities that dominate the area. This has led to dramatic decreases in the surface elevation of most Delta islands, most of which are now well below Mean Sea Level (MSL). As a result of the importance of the Delta and Suisun Marsh as an estuarine habitat, and the desire to evaluate the potential effects of water project operations and other factors affecting species and habitats within the estuary, extensive fishery and terrestrial monitoring has been conducted within the area over the past several decades. Results of these investigations provide insight into the hydrodynamics, water quality, habitat, species composition and seasonal and geographic distribution, and factors affecting aquatic and terrestrial species that form the scientific foundation for this risk assessment.

3.1 Aquatic Community

Freshwater enters the eastern side of the Delta via the Sacramento River (in the northeast), the San Joaquin River (southeast), and various tributaries such as the Mokelumne and Cosumnes Rivers (due East) (Figures 1a and 1b). Suisun Marsh, to the west of the Delta-proper, is a brackish tidal marsh where salinity varies seasonally and annually depending on freshwater flow from the Delta and local tributaries and tidal influence. Saltwater enters the Delta and Suisun Marsh from Suisun Bay and, ultimately, from the Pacific Ocean via the Golden Gate. Along the salinity gradient extending from the Golden Gate upstream into the Delta the aquatic biological community changes dramatically in response to the salinity preferences and tolerances of various aquatic species inhabiting the estuary (Figure 2).

Energy inputs into the Delta include solar radiation and exogenous organic matter (dissolved and suspended) transported into the Delta and Suisun Marsh from sources upstream. Figure 3 presents a simplified depiction of the food web. Energy sources and nutrients are used by primary producers and microbial decomposers to produce organic matter that forms the base of the aquatic food web. Primary producers (aquatic plants, photosynthetic bacteria, and protists) and microbial decomposers are preyed upon by primary consumers. Most consumers of primary productivity are zooplankton, including copepods, cladocerans, and clams. The primary consumers are, in turn, preyed upon by secondary consumers, consisting mainly of a variety of invertebrates (polychaete worms, snails, copepods, shrimp, clams (both native and invasive), and crabs), and fishes such as northern anchovy, Pacific herring, topsmelt, delta and longfin smelt, white croaker, flatfish, gobies, sculpin, threadfin shad, juvenile Chinook salmon, sturgeon, and a variety of other resident and migratory fish species. Top predators, including fish (e.g., striped bass, largemouth bass, inland silverside, catfish), marine mammals, birds, and humans prey on these secondary consumers. All species in the system also contribute to the formation of detritus, which is decomposed by microbes and consumed by detritivores (e.g., polychaete worms, amphipods, cladocerans, and a diverse group of other fish and macroinvertebrates).

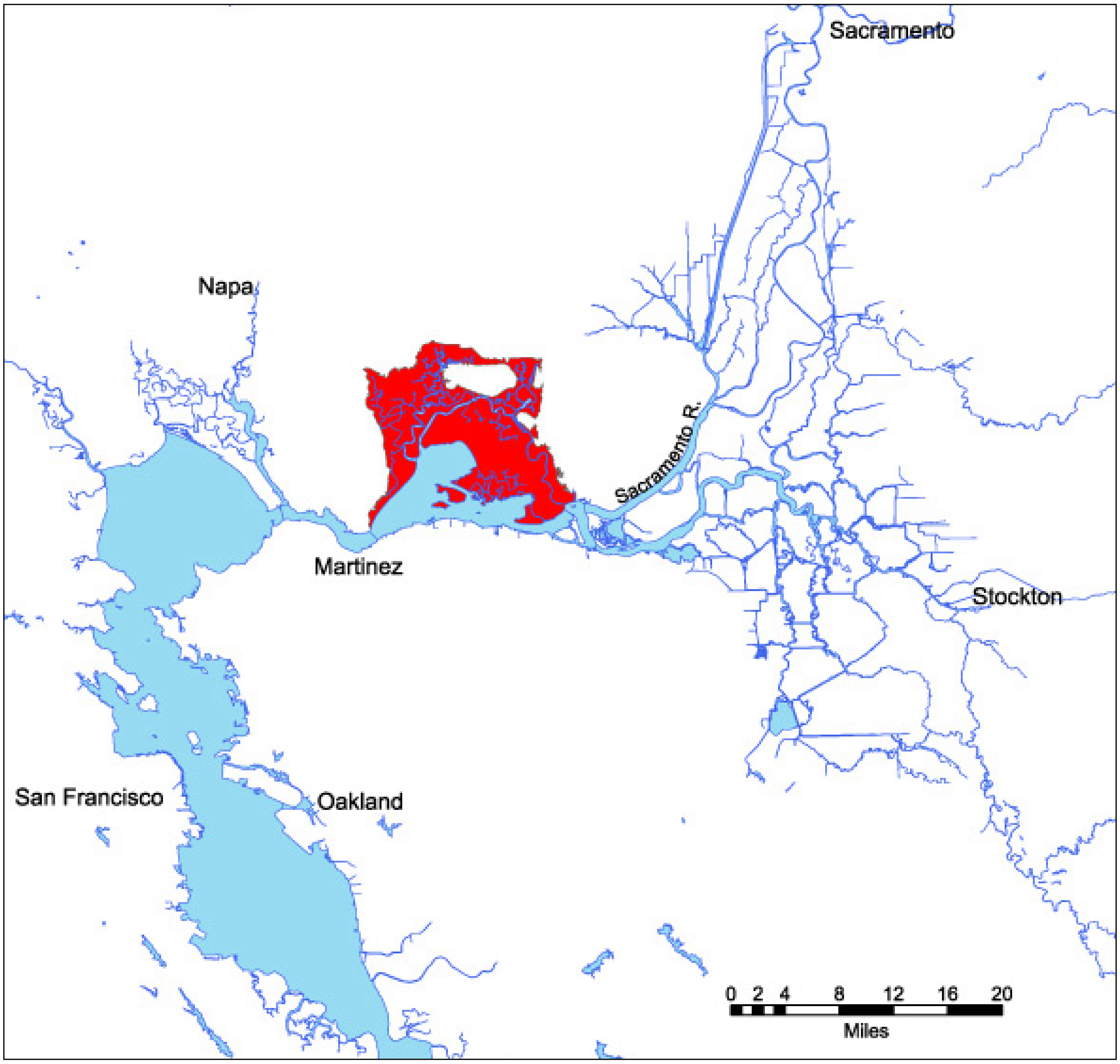

Figure 1a: The San Francisco Bay–Delta Estuary (Source: DWR 2002, based on USGS). Suisun Marsh is shown in red.

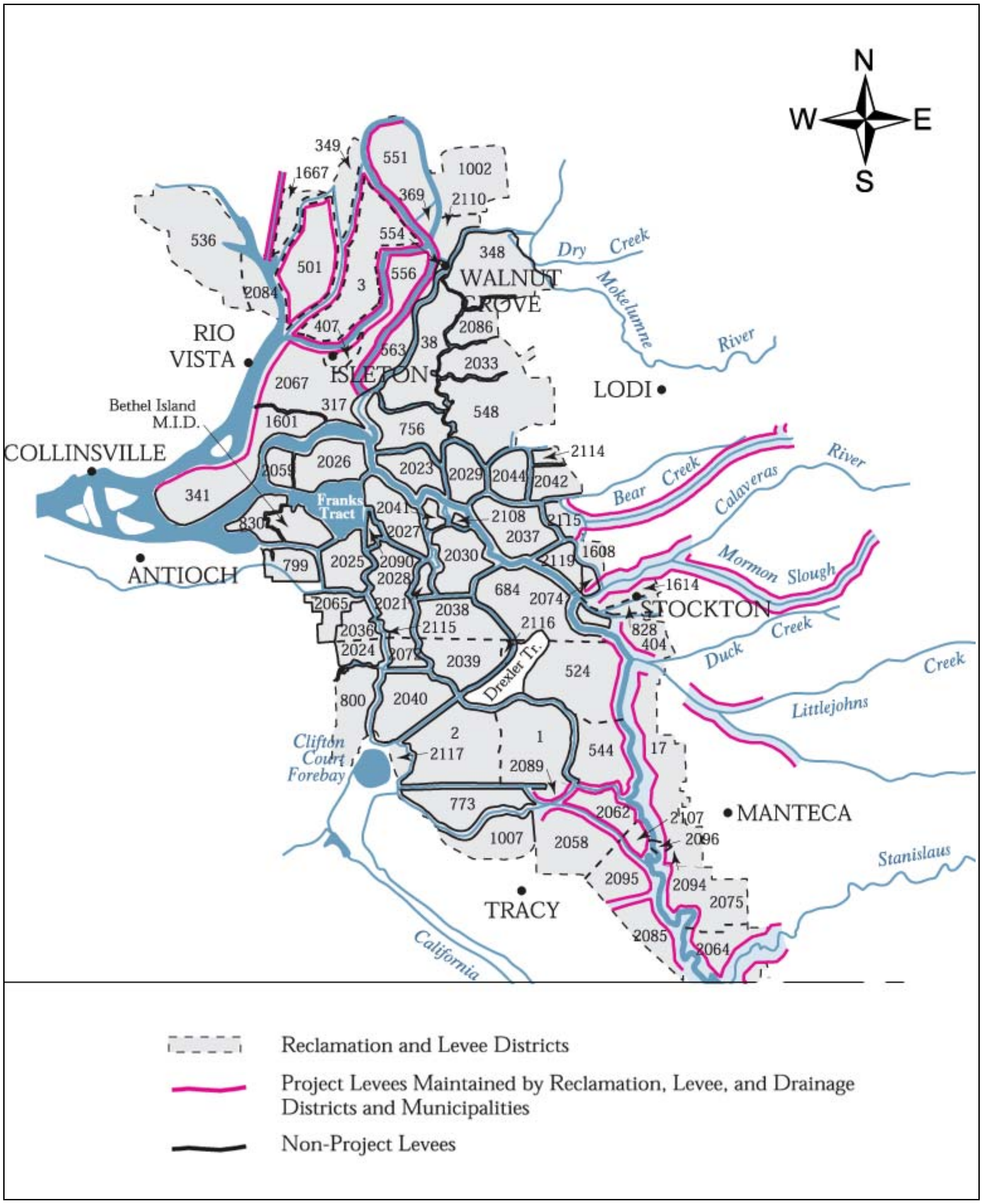

Figure 1b: Delta Islands and Levees, Showing Jurisdiction (Source: DWR 2002).

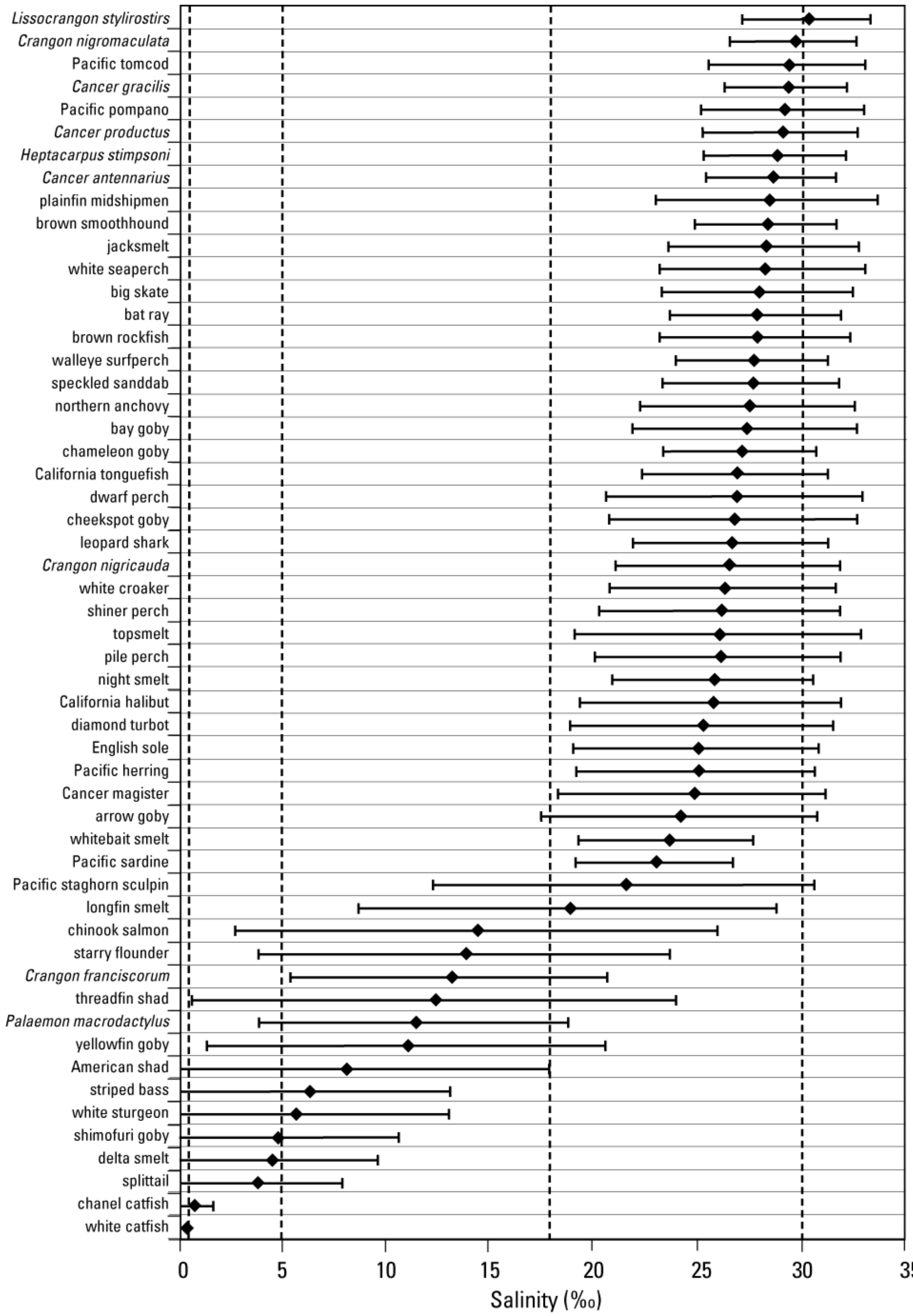

Figure 2: Mean Salinity (%o) +/- Standard Deviation for the 54 Most Common Species of Fishes, Shrimps, and Crabs Collected During the CDFG Bay Study, 1980–1995 (Survey Is Conducted Through Present) (Baxter 1999).

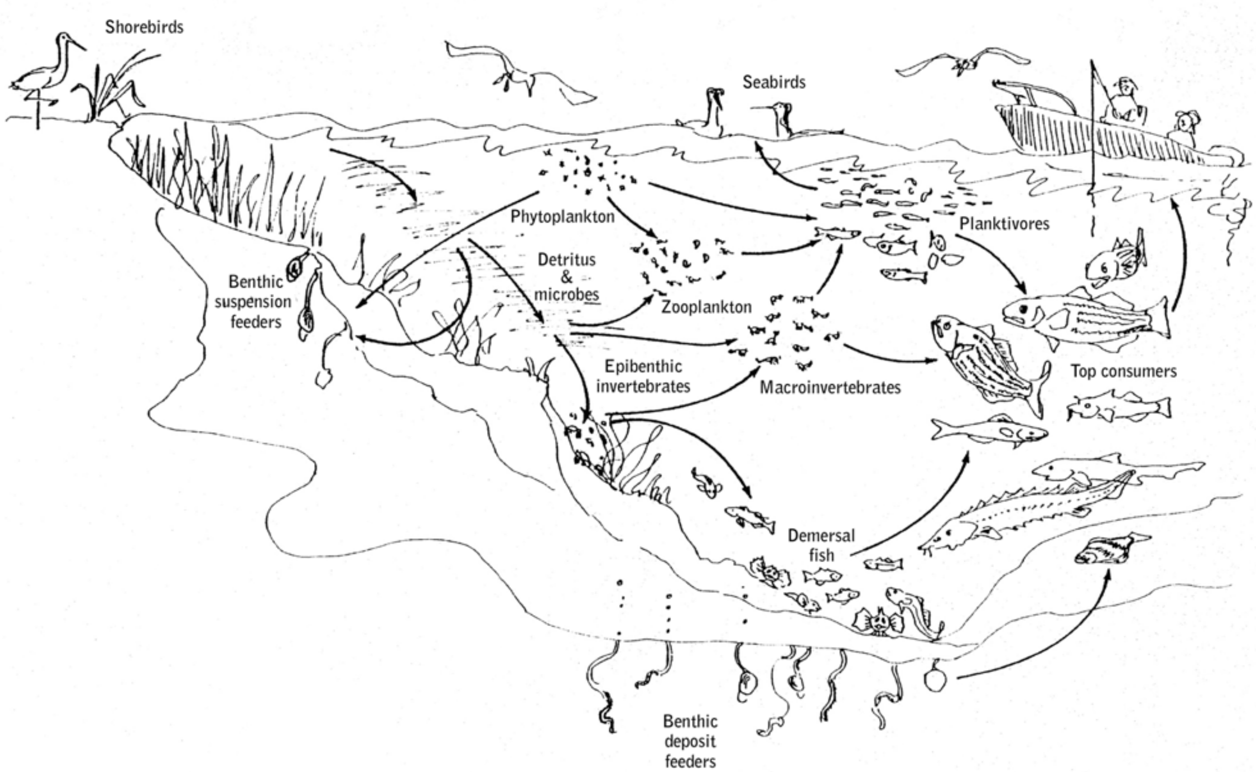

Figure 3: The Bay-Delta Aquatic Community and the Primary Feeding Relationships Among Community Components (Source: Ecological Analysts 1981; Adapted from CDFG 1964).

Like many aspects of the Delta and Suisun Marsh ecosystem, patterns of energy and nutrient flow are extremely complex and highly variable across time and space. The food web described above is an extremely simple depiction of reality. First the food web may have additional trophic levels where predatory fish are consumed by larger predatory fish. Also, the trophic position of many species changes throughout their life cycle. In addition, individual organisms may feed at several trophic levels simultaneously (i.e., primary and secondary consumers).

A wide variety of aquatic habitats are represented in the Delta and Suisun Marsh. These include fast-flowing (lotic) typically deep-water environments in both riverine and tidally influenced channels, and slow-moving (lentic) environments found in the Central Delta and Suisun Marsh as well as tidally influenced dead-end slough habitats around the periphery of both areas. These flow/depth categories favor different species and different life stages of those species; thus, the flow rate provides one axis that discriminates among different biological communities. These structurally different environments lie along tidal, salinity, water depth, and temperature gradients that produce geographic differences in community composition and productivity. In addition, because different life stages of single species may favor different habitats, species composition in different habitats is highly variable throughout the year.

Fish assemblage sampling programs within the estuary have shown that it supports approximately 55 fish species (Baxter 1999). About one-half of these are non-native, introduced species. Many of the non-native fish species inhabiting the estuary, such as striped bass and American shad, were purposefully introduced to provide recreational and commercial fishing opportunities. A number of the fish species (e.g., threadfin shad and inland silversides) were introduced accidentally to the estuary. In recent years several other fish species (e.g., yellowfin and chameleon gobies) have been accidentally introduced into the estuary, primarily from Asia, through ballast water discharges resulting from commercial cargo shipping. In addition, an estimated 100 macroinvertebrates (e.g., overbite clam, New Zealand mudsnail, Chinese Mitten Crab) have also been introduced into the estuary through ballast water discharge and the aquarium trade (Carlton 1979; Cohen 1998). Many of these introduced fish and macroinvertebrates have colonized and now inhabit portions of the Delta and Suisun Marsh. The purposeful and unintentional introductions of non-native fish and macroinvertebrates have contributed to a substantial change in the composition, trophic dynamics, and competitive interactions of the aquatic ecosystem of the estuary, affecting the population dynamics of native species. Going forward, the population dynamics of these non-native species (e.g., increasing populations and continued range expansion) and the likelihood of continued introductions of new non-native species represent significant sources of uncertainty for predicting future states of the Delta aquatic ecosystem.

Over the past several years many of the pelagic fish species inhabiting the Delta and Suisun Marsh, such as delta smelt and longfin smelt, have experienced a significant decline in abundance referred to locally by regulatory agencies, scientists, and stakeholders as the *pelagic organism decline* (POD). The forces contributing to the POD are hypothesized to include changes in seasonal hydrology (due to long-term climatic changes and water export project operational changes), competition from or predation by introduced species, exposure to toxic substances (especially pesticides), and other factors. State and Federal resource agencies are actively investigating the significance of these and other factors affecting pelagic fish species, their population dynamics, habitat suitability, and the overall condition of the Delta and Suisun Marsh. To date, the relative importance of each of these factors on populations of pelagic species has not been determined. Discriminating direct impacts and interactions among the multiple potential drivers of the POD is difficult and contributes to the uncertainty surrounding predictions of future states of the estuaries aquatic ecosystems.

3.2 Plant and Wildlife Communities

The Delta and Suisun Marsh support a diverse community of submerged aquatic vegetation (SAV), emergent and wetlands, managed wetlands, riparian plants, agricultural crops, and upland communities and associated wildlife communities. Vegetation communities within the Delta and Suisun Marsh occur in a patchy mosaic consisting of broad zones that are generally determined by abiotic gradients. Salinity and water depth define the principal abiotic gradients that influence vegetation within the Delta and Suisun Marsh. Variation in salinity results in plant communities ranging from halophyte dominated areas to freshwater and terrestrial communities that cannot tolerate salts. Variation in depth and duration of flooding results in plant communities ranging from aquatic submerged vegetation to a wide array of wetlands and uplands.

Distributions of, and variation among, plant communities are further influenced by the presence or absence of tidal action, such as the differences between diked and tidal marshes, and human impacts, such as agricultural history or levee construction. Furthermore, the Delta and Suisun Marsh plant communities include both herbaceous and woody species. Like most of California, the Delta and Suisun Marsh ecosystem supports a high percentage of non-native and invasive plant species; at least 70 non-native plant species occur in the Delta. The changes in water levels, tidal inputs, and salinity that would result from levee failures in the Delta and Suisun Marsh would affect the integrity and distribution of vegetation communities.

The Delta and Suisun Marsh vegetation communities are an integral part of the overall ecosystem. Vegetation provides both a primary food source and physical structure for wildlife species. Vegetation zones, therefore, tend to characterize habitat value for wildlife. Wetland communities, which are prevalent in Suisun Marsh (Suisun Marsh contains 12% of the natural wetlands remaining in California), provide societal values that include flood storage and retention, nutrient production and transport, hunting, and recreation. Wetlands also provide a buffer and filter improving water quality. Suisun Marsh is the largest contiguous brackish water marsh remaining on the west coast of North America. The marsh is comprised of 52,000 acres of non-tidal (managed) wetlands, 6,300 acres of tidal wetlands, 27,700 acres of upland grassland, and 30,000 acres of bays and sloughs.

The Delta and Suisun Marsh ecosystem supports dozens of species of resident and migratory wildlife, including birds, mammals, reptiles, and amphibians. Until European settlement, the Delta was dominated by tidal marsh (e.g., the Delta was estimated to support approximately 400,000 acres of tidal marsh prior to reclamation efforts), with extensive riparian forests distributed along the floodplains of its tributaries. Today, the species composition, distribution, and abundance of wildlife in the Delta and Suisun Marsh are determined primarily by the distribution and extent of suitable habitats. The major change in Delta and Suisun Marsh habitats from historical conditions has been the loss of tidally influenced wetland habitats with construction of levees and dikes and the conversion of marsh and riparian communities to agricultural uses. Consequently, the distribution and abundance of resident marsh- and riparian-associated species has declined (e.g., California black rail, salt marsh harvest mouse, western yellow-billed cuckoo). The distribution and abundance of species for which agricultural lands provide habitat have been less severely affected or benefited.

The Delta and Suisun Marsh currently provide habitat for a diverse assemblage of resident (year-round) birds and wildlife, and migrant wildlife (e.g., summer neotropical migrants, winter migrants). In addition to resident wildlife, the Delta and Suisun Marsh serve as a wintering and migration stopover habitat for a large proportion of waterfowl, sandhill cranes, and shorebirds of the Pacific Flyway. Delta and Suisun Marsh habitats (e.g., managed wetlands, tidal marshes, tideflats, agricultural lands) provide these species with the food resources needed to sustain their populations during the winter and the energy reserves necessary to sustain migration and initiate breeding on their nesting grounds.

3.3 Sources of Uncertainty Regarding Delta/Suisun Marsh Fish and Wildlife

Although substantial effort has been made to study and collect data on the species, habitats, and ecological processes in the Delta and Suisun Marsh, the state of knowledge on some subjects is quite limited. Our understanding of critical attributes of species, habitats, and processes in the estuarine ecosystem is patchy. While some species have been extensively studied, others are lacking significant and or current information. As a result, it is difficult to construct quantitative predictive models that accurately estimate the effects of environmental disturbances or predicted future conditions. The gaps in our knowledge base (basic data and scientific understanding) are a source of epistemic uncertainty (uncertainty related to lack of knowledge). Observational experience and long-term scientific studies also suggests that there is significant randomness in ecological processes, producing aleatory uncertainty as well (uncertainty related to the randomness of events).

As described above, the Delta and Suisun Marsh provide habitat to a diverse assemblage of resident and migratory estuarine organisms. A wide range of habitats, created by the interaction of physical forces (e.g., flow rates, tidal influence, water depth, salinity intrusion, temperature) with different primary producers (that influence both the local energy supply for other trophic levels and the physical structure of the habitat), and human activities (e.g., agriculture, suburban housing, managed diked-wetlands) leads to a geographically complex pattern of species assemblages. Furthermore, many species use the Delta and Suisun Marsh as a migration corridor, while other species are year-round residents that use different habitats throughout their life cycle. This physical, biological, geographical, and temporal complexity makes biological sampling and analysis challenging. For example, even intensive sampling efforts may fail to capture important associations between species and habitats that happen seasonally or in a particular environment whose location changes seasonally or annually (e.g., based on freshwater outflow). Fortunately, several long-term and intensive fish and wildlife sampling programs such as those conducted by the California Department of Fish and Game (CDFG), US Fish and Wildlife Service (USFWS), California Department of Water Resources (DWR), US Geological Survey (USGS), University of California, Davis (UCD), and others have created data sets that are valuable for the study of biological trends and relationships within the Delta and Suisun Marsh.

In the Delta and Suisun Marsh, key unknowns that contribute to our epistemic uncertainty for many of the species include (but are by no means limited to):

- Current or historical population abundance and relationships (e.g., linear, logarithmic) between population indices and actual population abundance;
- Basic life history data (e.g., fecundity and mortality rates);
- Physical habitat tolerances and preferences (salinity, temperature, dissolved oxygen, turbidity, pollutants);

- The strength, extent, and natural variability in biological interactions including predator-prey dynamics, diseases and their epidemiology, and competitive interactions; and
- The carrying capacity of the Delta and Suisun Marsh, the trends in carrying capacity, and the drivers that produce those trends.

In general, these and other knowledge gaps extend across species, habitats, and trophic guilds. Uncertainty regarding these factors is less for some species than for others. For example, upstream counts of spawning adult Chinook salmon are considered to be relatively reliable indicators of the numbers of adults that migrate through the Delta each fall and winter. Similarly, some life history variables for some species have been studied intensively. Also, the physical habitat tolerances for certain species (e.g., water temperature for Sacramento splittail; salinity for delta smelt) are reasonably well known. Finally, there is general agreement regarding the importance of certain physical drivers (i.e., freshwater outflow during the spring, as measured by "X_2" location) on the geographic distribution and characteristics of estuarine habitat, however there is epistemic uncertainty in the biological response of many species to changes in estuarine habitat conditions (e.g., a change in X_2 location). Still the number of important features of this ecosystem that have been studied successfully is dwarfed by those for which there are little or no data. Further, factors such as population abundance and the strength of density-dependent limits on population growth can only rarely be determined precisely (May 1974). As a result of these constraints and uncertainties, we are not proposing to develop individual based predictive models, population dynamics models, or ecosystem level models for aquatic or terrestrial species selected as part of this analysis.

In addition to the epistemic uncertainty surrounding predictions of ecosystem response to environmental perturbations, predictions of this sort in biological systems are also subject to significant aleatory uncertainty. Chance events play an important role in population dynamics, interactions among species, and other environmental processes. The forces that produce aleatory uncertainty become increasingly important as population abundance decreases ("Allee effects", Stephens and Sutherland 1999) or the geographic extent of a critical habitat declines (e.g., Rosenfield 2002). Many of the species and habitats included in the environmental risk analysis component of the DRMS project are small, geographically limited, and endemic or extremely isolated. Thus, aleatory uncertainty is expected to have a relatively large impact on the predictions that will result from this analysis.

The relationships between the availability of terrestrial species habitats (i.e., extent, connectivity, patch sizes, and quality [e.g., availability of food items per unit area of habitat]) and the distribution and abundance of wildlife in the Delta and Suisun Marsh are generally well understood. The data necessary to quantify these relationships, however, is often lacking (e.g., the likely effects of a change in food availability on a species distribution, behavior or abundance). Other factors such as the direct and indirect effects of toxic substances, predation and competition with introduced species, and changes in water quality and water operations on the distribution and abundance of fish and wildlife species inhabiting the Delta and Suisun Marsh are characterized by a high degree of uncertainty. .

Due to the limited nature of our knowledge about critical aspects of species, habitats, and ecosystem processes, the published information on these subjects is generally inadequate to support the task of constructing quantitative predictive population-level or ecosystem-level effects models for aquatic and terrestrial species and their responses to changes in habitat conditions that may occur in response to levee failures and island flooding. For these reasons, the analysis of environmental consequences will not attempt to model changes in ecosystem dynamics or functions. Rather, the framework for the environmental risk assessment is based in large part on the principles developed through the USFWS Habitat Evaluation Process (HEP). Section 4 provides more detail regarding the environmental risk analysis framework as one component in the overall integrated DRMS levee failure investigation.

To generate parameter estimates (and the level of uncertainty surrounding these estimates), the analysis will rely, in part, on expert input to the risk assessment. Two types of experts will be used to contribute to the development of the assessment. "Resource specialists" will be contacted and interviewed individually to obtain data and insights regarding species responses to environmental conditions such as salinity or water depth preferences. "Evaluation experts" will contribute to the review of the initial framework for analysis of risk based on results for a set of levee failure scenarios. The manner in which experts will be used in this process is described in more detail in Section 4.

4.0 ENVIRONMENTAL EFFECTS EVALUATION PROCESS

The ability to estimate the environmental effects of levee failures is limited by our current state-of-knowledge of ecological processes in general, and the impact that significant stressing events such as levee failures may have in particular. Like other areas considered in the DRMS risk analysis (e.g., levee vulnerability, hydrodynamic response, economics), where observational evidence, theoretical models, and modeling experience provide the opportunity and capability to make quantitative, probabilistic assessments (albeit with uncertainty), determining the level of uncertainty in predicted outcomes of a levee failure is also and important aspect of the environmental risk analysis. As such, in the environmental consequence analysis, a process must be used that captures the present state-of-knowledge and understanding as to the impact (positive or negative) that levee failures may have on selected representative species inhabiting the Delta and Suisun Marsh.

The proposed framework for the environmental analysis will utilize the best scientific and technical data available from studies conducted within the Delta and Suisun Marsh and elsewhere, as well as expert evaluations to support the development of predictive models that are required as part of the DRMS risk analysis. The ITF for the environmental risk analysis is briefly described below. As with most environmental analyses we expect that the framework will be modified and refined over time as additional information is compiled, synthesized, and integrated into the risk assessment framework.

4.1 Environmental Analysis Framework

Levee failures within the Delta or Suisun Marsh have the potential to affect fish and wildlife species directly (e.g., mortality to individual fish entrained onto a flooded island, removal of vegetation during a levee break or as a result of levee reconstruction) or indirectly (e.g., changes in the amount or quality of habitat, water quality, or changes in upstream water releases and diversions from the Delta). Changes in habitat conditions may be detrimental to some species or lifestages and beneficial to others. Also, changes may have different effects depending on the geographic location and extent of the change, and the timing and duration of the occurrence (some effects may occur over a relatively short time frame [days to months], while others may occur over longer time frames [years to decades]).

As part of development of the environmental risk analysis framework a conceptual model has been developed to identify the potential mechanisms by which levee failures could affect aquatic and terrestrial species inhabiting the estuary. The effect mechanisms have been matched with the selected target species to define the biological relationships to be included in the analysis. The following sections briefly describe the framework and approach that will be used in the environmental consequence analysis.

Mechanisms of Effect

One of the primary challenges in developing the framework for the environmental risk analysis was the identification of a suite of environmental parameters that provide representative and meaningful information on predicted environmental effects, both positive and negative, associated with a wide range of levee failure scenarios. Environmental parameters such as changes in salinity or an increase the extent of flooded habitat with suitable water depths that may result from a levee failure were identified for inclusion within the framework (Figure 4) since the biological responses of various species to these changed conditions are relatively simple to interpret but detect meaningful environmental effects. Consideration has also been given to developing indicators that can be used in combination with the suite of individual effects metrics to identify thresholds of levee failure that result in significant environmental effects, and identify key areas and seasonal periods within the Delta and Suisun Marsh that are most environmentally sensitive.

The framework for analyzing potential effects to aquatic and terrestrial species has focused on the direct effects to aquatic species resulting from entrainment and changes, both beneficial and detrimental, to habitat suitability for aquatic or terrestrial species as a result of flood inundation (e.g., water depth, hydraulic residence time, etc.) and water quality (e.g., salinity, water temperature, suspended sediment concentrations, dissolved oxygen concentrations, exposure to toxic contaminants, etc.). Examples of the framework formulation for both entrainment effects and changes in habitat suitability are presented below.

<u>Entrainment</u>

Fish and other aquatic organisms inhabiting the Delta or Suisun Marsh within the area adjacent to a levee failure would be vulnerable to entrainment onto the flooded island. Planktonic fish eggs and larvae and small juvenile fish would be most susceptible to entrainment as a result of their reduced swimming performance capability. Fish and other aquatic organisms entrained onto a flooded island immediately after a levee breach would experience potentially stressful and/or unsuitable habitat conditions. No information is available from the scientific literature on the survival of fish entrained onto a flooded island. As a conservative (worst-case) condition the environmental risk assessment will assume that no fish initially entrained onto an island at the time of a levee breach will survive. To estimate entrainment mortality on selected fish species, data on the average monthly density (number of fish per acre-foot of water) was calculated from results of CDFG fishery surveys within the Delta and UCD surveys from Suisun Marsh from sampling stations within various regional areas of the estuary (Figure 5). Data used in calculating fish densities was limited to surveys during the period from 1995 through 2005 to represent recent hydrologic and management actions (e.g., Delta Accord and D-1641) within the estuary. The estimated number of a species of fish entrained onto a flooded island will be calculated as shown in Figure 6. The proportion of the standing stock of a species lost as a result of entrainment will be estimated using data on the average density of the selected species within each region of the estuary and the water volume within the region, as shown in Figure 7. Using the standing stock estimate and the estimated number of a selected species lost to entrainment a percentage of a year class lost can be estimated (note that the estimate also takes into account the seasonal timing of levee breaching and the proportion of a year-class potentially within the Delta or Suisun Marsh at the time of the levee failure. The percentage of a year-class lost to entrainment can then be used in a probability of extinction analysis similar to that shown in Figure 8 to estimate the potential significance of entrainment as a population-level factor affecting a selected species. The loss of individuals as a result of entrainment onto a flooded island would be considered an adverse effect as a result of increased mortality.

Fish inhabiting the Delta are also vulnerable to entrainment onto existing islands through a large number of unscreened diversions used to supply water for irrigation. Information on the number and location of water diversions (both pumped diversions and siphons) is available from surveys conducted by CDFG. A generalized agricultural irrigation schedule will be developed and used in combination with information on points of diversion to estimate the seasonal volumes of water diverted onto an island before a levee breach (baseline) and the period when no diversions would occur while the island remains flooded and during reclamation (see Figure 6). Estimates of reduction in entrainment losses would be calculated using the average monthly fish density from the region and the reduction in monthly diversions while the island is flooded compared to baseline conditions. The reduction in entrainment loss would be considered to benefit a species through reduced mortality.

Fish are also vulnerable to entrainment and salvage losses resulting from SWP and CVP export facility diversions from the Delta. Operation of the SWP and CVP export facilities may be reduced in the event of a levee failure as a result of increased salinity intrusion into the Delta or other potentially adverse water quality conditions. As part of the environmental risk assessment estimates will be made of the entrainment/salvage of selected fish at the SWP and CVP exports under baseline conditions and in response to a levee failure. The average monthly species-specific densities and modeled monthly diversions will be used to estimate entrainment as shown in Figure 9. Net entrainment losses for changes in SWP and CVP entrainment losses and the losses as a result of entrainment onto the flooded islands will be calculated as shown in Figure 10. A reduction in entrainment losses at the SWP and CVP export facilities as a result of a levee failure would be considered to be an environmental benefit.

Indices of entrainment losses, both increased adverse losses and environmental benefits from reduced entrainment losses will be generated as part of the environmental risk analysis. The overall net change in entrainment losses for a selected species will be used as an indicator of the environmental effects of levee failure on fish entrainment mortality.

Environmental Risk Assessment (Fish)

- Direct effects
  - Island Entrainment
- Indirect effects
  - SWP/CVP entrainment/salvage
  - X2 location
  - Habitat Quality
    - Duration of availability
    - Water depth
    - Salinity
    - Temperature hydraulic
    - Residence time
    - Colonization by exotics (e.g., egeria, corbula)
    - Vulnerability to predation
    - Turbidity/suspended sediment

Figure 4: Mechanisms of Effect on Aquatic Species.

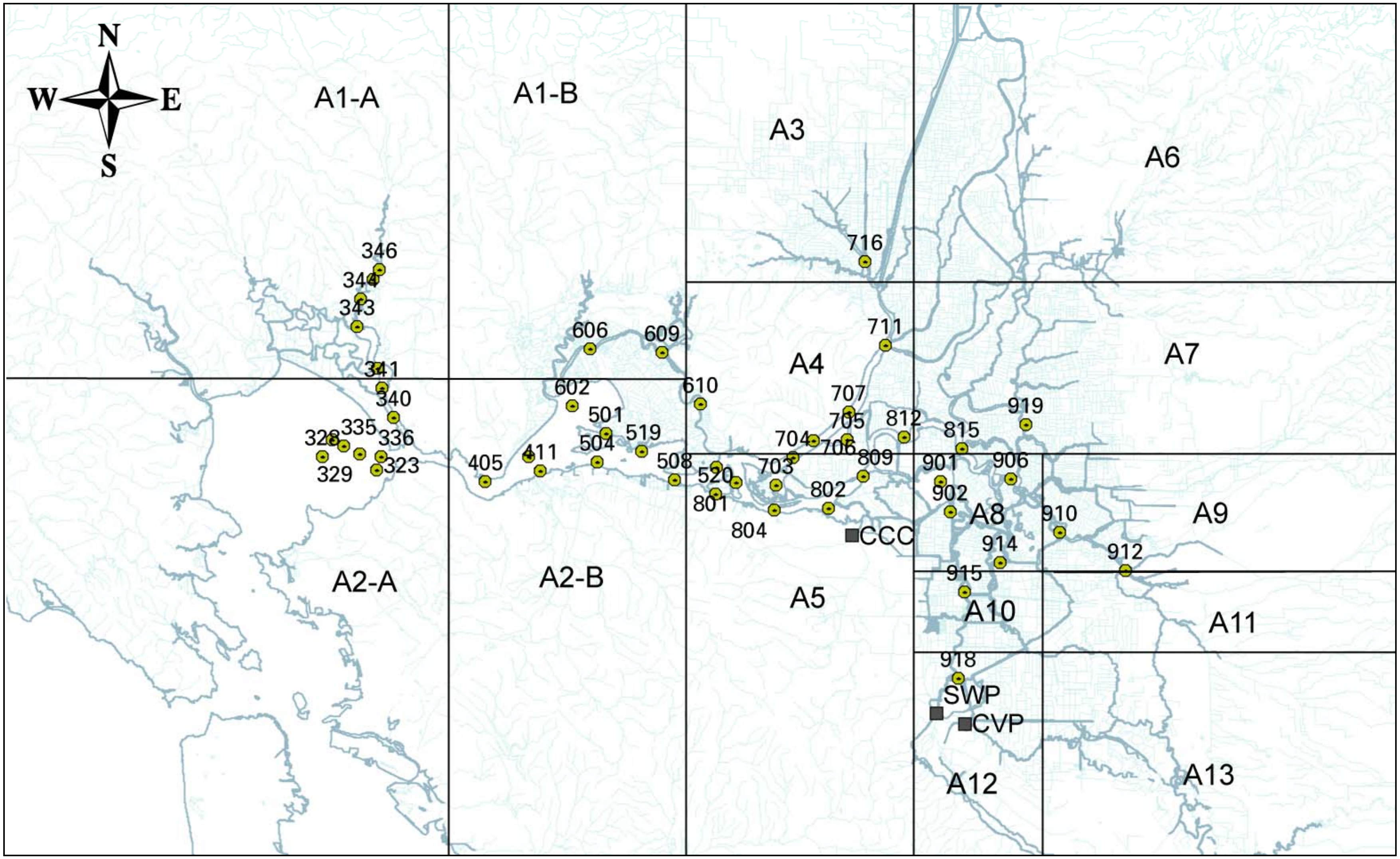

Figure 5: Regions of the Delta and Suisun Marsh Included in the Risk Analysis.

$$\left[\text{Density (NO/AF) within region during month of breach}\right]\left[\text{Water volume (AF) entrained onto island}\right] = \textbf{(number of fish lost)}$$

Figure 6: Fish Entrainment onto a Flooded Island.

$$\sum\left[\text{Density (NO/AF) within each region}\right]\left[\text{Water surface area (acre)}\right]\left[\text{Mean water depth (ft)}\right]$$

= Standing stock

% Loss = [(Number fish lost)/standing stock] 100

$$\textbf{Impact Index Score = } \boldsymbol{F}\left[\textbf{\% loss and response curve}\right]$$

Figure 7: Framework for Estimating the Percentage Entrainment Loss for a Species.

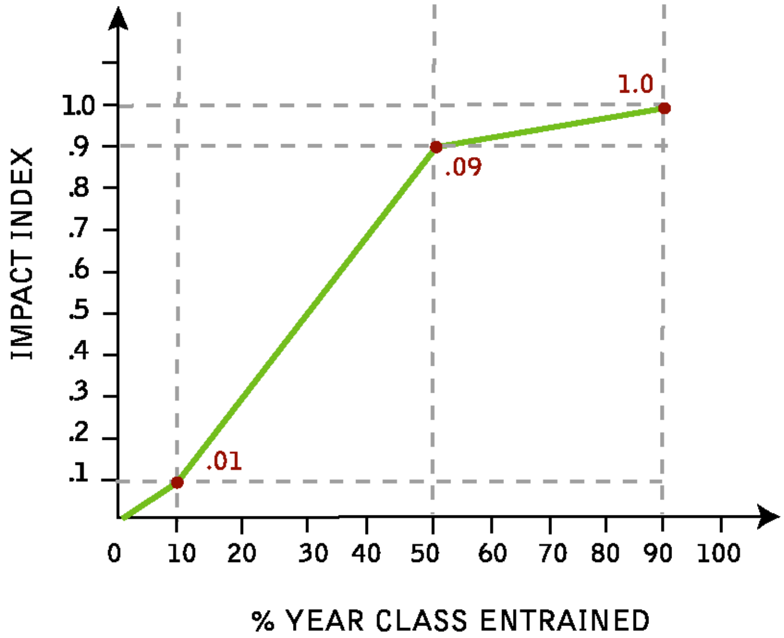

Figure 8: Framework for Estimating the Population-Level Significance of Entrainment Mortality.

$$\sum \left[\begin{array}{c}\text{Average}\\ \text{monthly}\\ \text{density}\\ \text{(NO/AF)}\end{array} \right] \left[\begin{array}{c}\text{Monthly}\\ \text{Export}\\ \text{(AF)}\end{array} \right]$$

= entrainment index over period of WQ change baseline and breach

$$\textbf{\% Change =} \left[\begin{array}{c}\textbf{SWP/CVP}\\ \textbf{Entrainment}\\ \textbf{Index}\end{array} \right] / \left[\begin{array}{c}\textbf{SWP/CVP}\\ \textbf{Baseline}\\ \textbf{Index}\end{array} \right] \textbf{100}$$

Figure 9: Framework for Estimating Changes in the SWP and CVP Fish Salvage.

SWP/CVP Baseline Index + SWP/CVP Entrainment Index - Island Entrainment Loss = Net Loss

$$\% \text{ Change} = \left[\text{Net Loss} \right] / \left[\text{SWP/CVP Baseline} \right]_{100}$$

Figure 10: Framework for Estimating Net Entrainment Loss for a Species.

<u>Habitat Suitability</u>

Levee failure results in localized changes in the suitability of habitat within the Delta and Suisun Marsh affecting, both adversely and beneficially, habitat quality and availability for various aquatic, terrestrial, and wildlife species. The framework for analyzing effects of levee failure on habitat conditions for selected fish species described below serves as a model for the general methods and approach that will also be used to assess effects of levee failure on terrestrial vegetation and wildlife as part of the environmental risk analysis. The specific parameters, time periods for effects, and indictor metrics will vary among species groups but the overall process of analysis is expected to be similar.

Habitat suitability of a flooded island following a levee failure for aquatic species is influenced by a variety of factors. For purposes of the environmental risk analysis the suitability of flooded island habitat is considered to be a function of salinity, water temperature, and water depth, as shown in Figure 11. Information is available from the scientific literature that can be used to develop habitat suitability curves for the selected species to be included in the risk analysis. The habitat suitability curves are each scaled fro 0 designating unsuitable habitat conditions to 1.0 designating suitable habitat conditions for a specific species and lifestage to a given environmental parameter. Examples of habitat suitability curves for delta smelt are shown in Figures 12–14. Results of the occurrence of a species within areas of the Delta during monitoring surveys conducted by CDFG can also be used to develop relationships between specific habitat parameters and habitat use by the species of interest (Figures 15a and 15b). As part of the environmental risk analysis habitat curves derived from both the scientific literature and results of field sampling will be used to characterize the biological response of a species to conditions that may occur as a result of levee failure but can also be used to assess the uncertainty in the relationships for inclusion in the analysis. In addition to the habitat suitability relationships for specific parameters such as

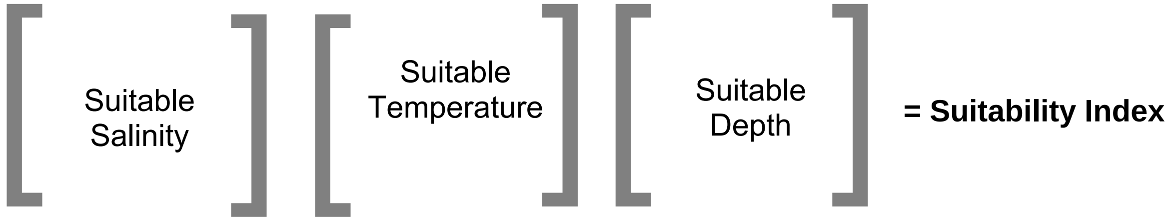

Figure 11: Habitat Suitability Parameters for Aquatic Species.

water temperature, salinity, or depth, relationships will also be developed for habitat suitability as a function of the duration that a levee breach remains open (Figure 16) and hydrologic residence time within a flooded island (Figure 17). The environmental risk analysis will also consider the interaction among several species such as the potential for increased vulnerability of fish to increased predation within a flooded island if *Egeria* has colonized the area. These and other relationships between indicators of habitat quality and availability will be used, in combination with various levee breach scenarios, to assess the potential environmental effects of changes in habitat within the Delta and Suisun Marsh. Indices of changes in habitat availability will be generated and presented for selected species to assess environmental effects of levee failure on aquatic, terrestrial, and wildlife species inhabiting the Delta and Suisun Marsh.

Levee failure may also changes the hydrodynamics within the Delta and salinity gradient within the estuary. Salinity has been found to be an important factor affecting the geographic distribution of aquatic species (Baxter 1999) within the estuary as well as various plants and wildlife species. One indicator of estuarine habitat that is commonly used within the Delta is the location of the 2 ppt salinity isohaline (X2 location) as measured in kilometers from the Golden Gate Bridge. Results of the hydrodynamic modeling for each levee breach condition provide information on the seasonal changes in X2 location that will be used as one of the indicators of habitat change for selected aquatic species within the estuary. Information on changes in salinity intrusion into Suisun Bay as a result of a levee failure condition within the Delta will also be used in the environmental risk analysis as an index of potential changes in terrestrial and wetland vegetation within Suisun Marsh and associated changes in wildlife associated with various vegetative habitats located within the marsh. Indicators of changes in aquatic, terrestrial, and wildlife habitat in response to a levee failure will be used in the environmental risk analysis to assess the potential significance of environmental disruption on selected species inhabiting the Delta and Suisun Marsh. These indicators will be presented separately for each of the selected species to identify those environmental changes that are

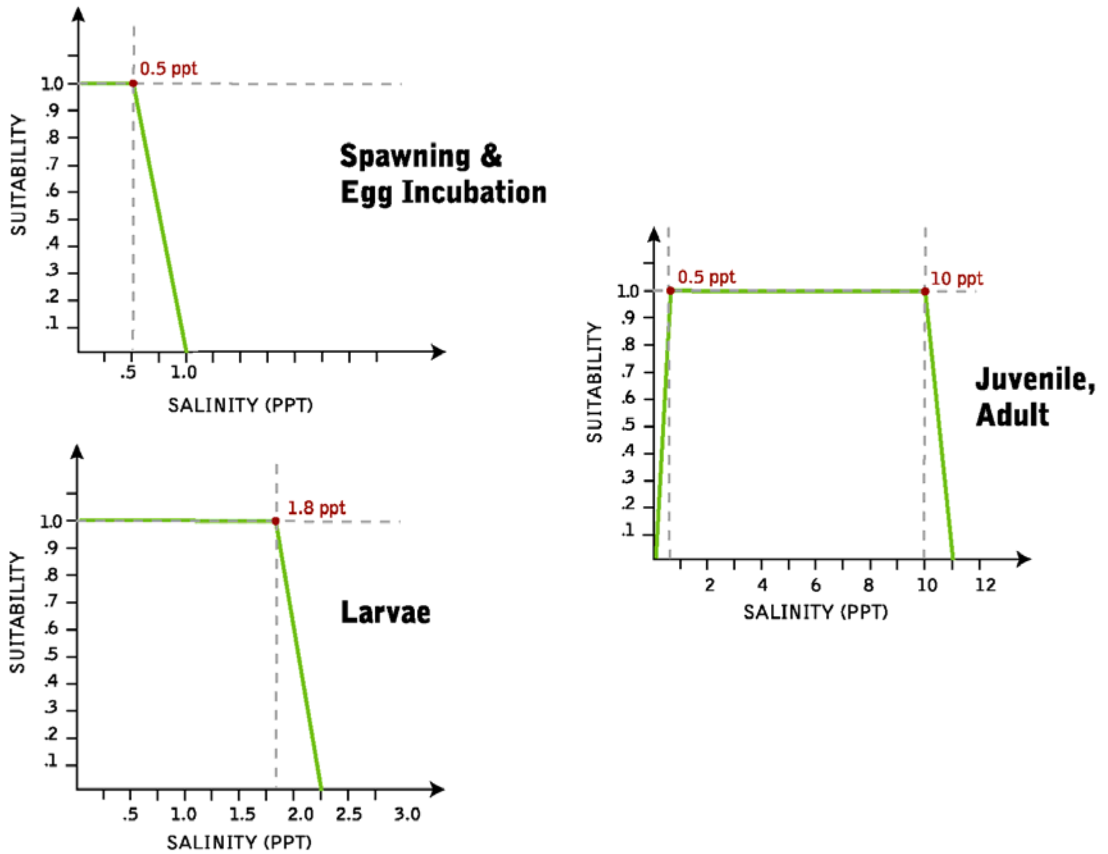

Figure 12: Example of Habitat Suitability for Different Lifestages of Delta Smelt to Salinity.

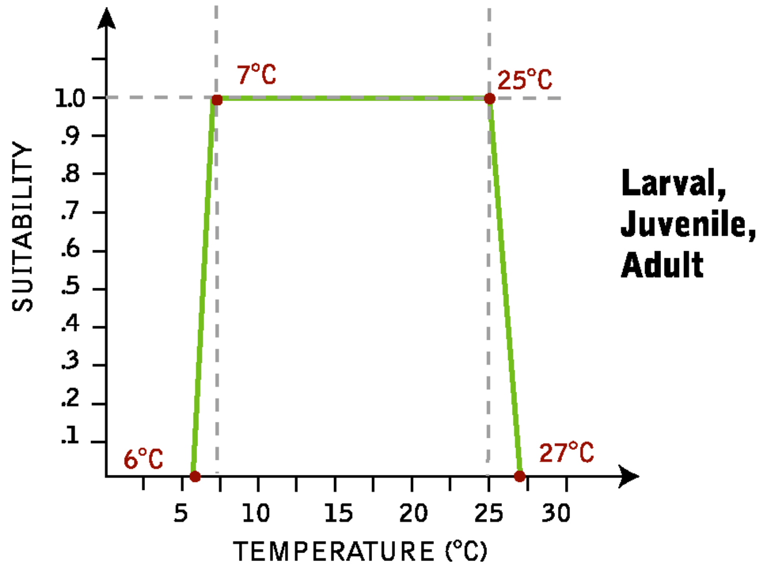

Figure 13: Example of Habitat Suitability for Different Lifestages of Delta Smelt to Water Temperature.

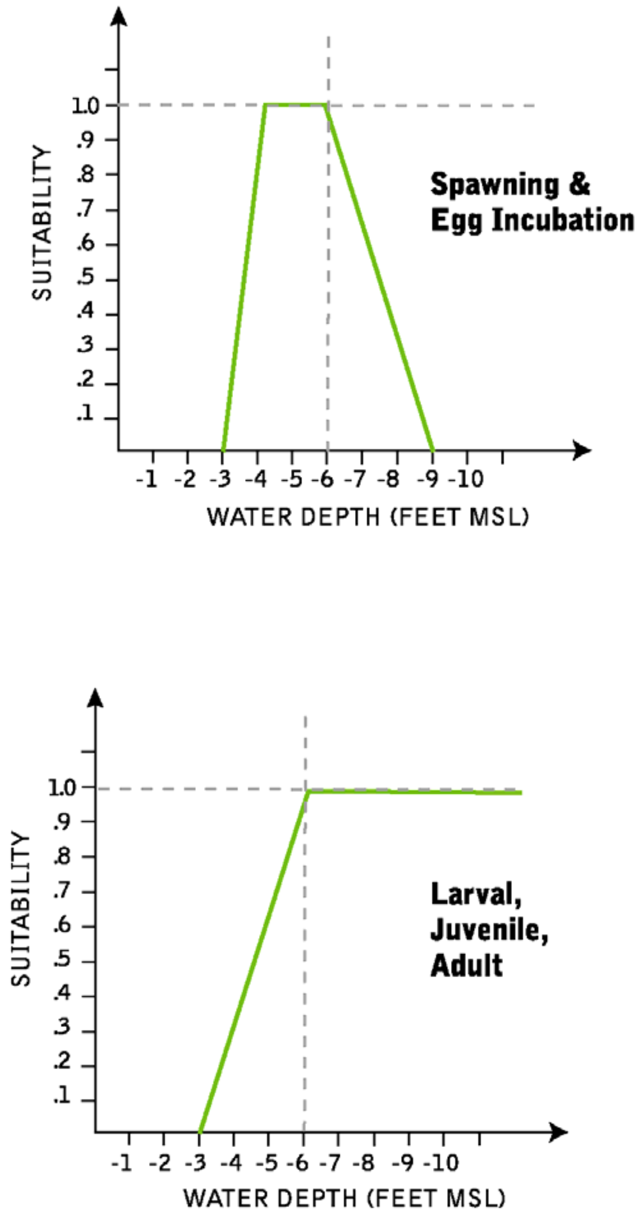

Figure 14: Example of Habitat Suitability for Different Lifestages of Delta Smelt to Water Depth.

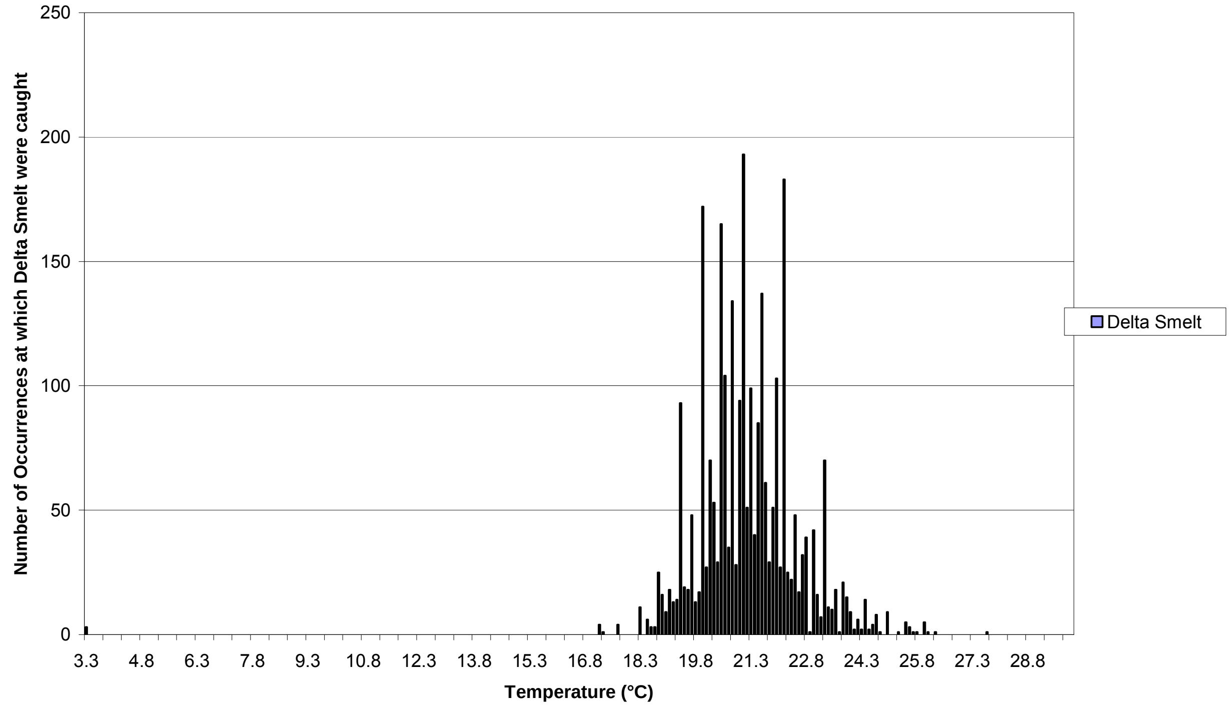

Figure 15a: Occurrence of Delta Smelt in the CDFG Summer Townet as a Function of Water Temperature.

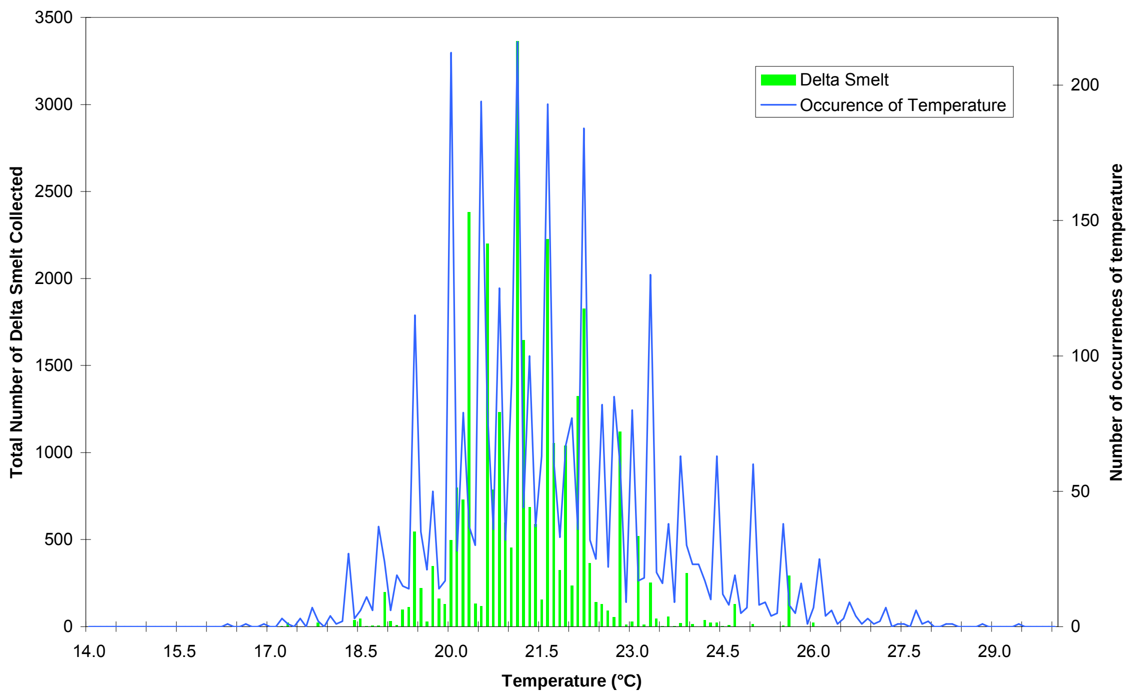

Figure 15b: Occurrence of Delta Smelt in the CDFG Summer Townet as a Function of Water Temperature.

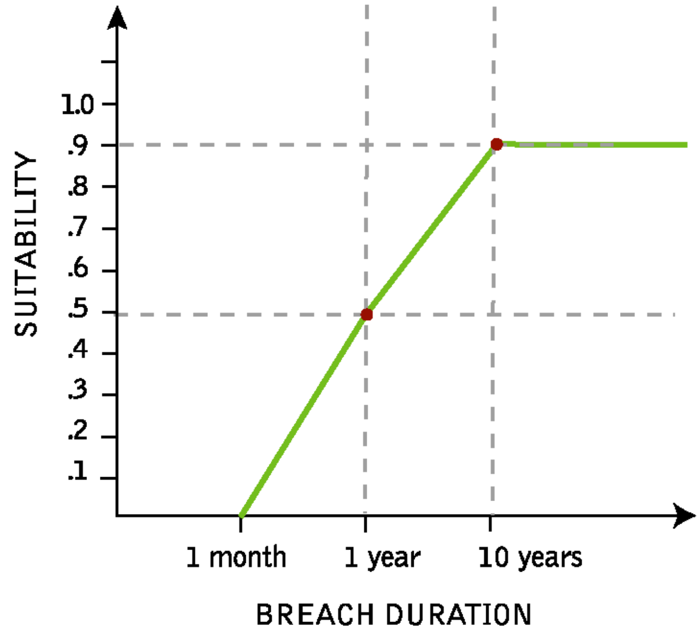

Figure 16: Example of the Relationship Between Breach Duration and Habitat Suitability for Delta Smelt.

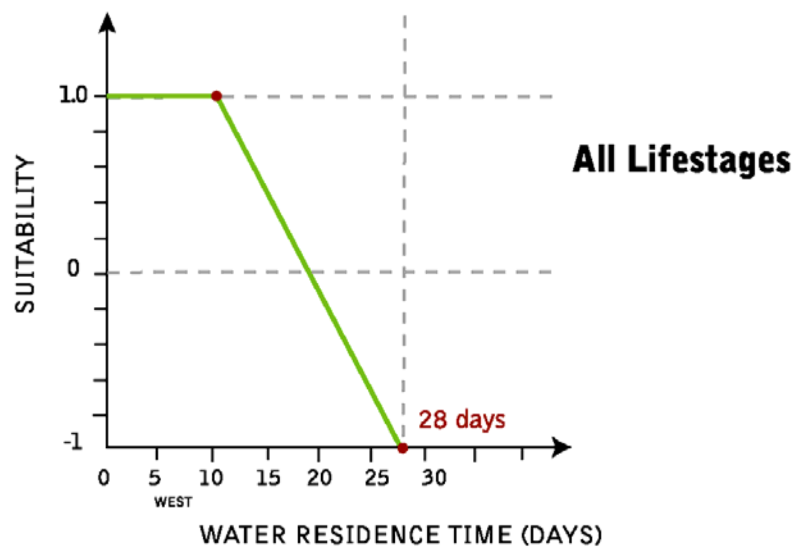

Figure 17: Example of the Relationship Between Hydraulic Residence Time Within a Flooded Island and Habitat Suitability for Delta Smelt.

adverse to a species and those changes that benefit or enhance habitat conditions for a species.

Levee failure within the Delta, and associated changes in SWP and CVP exports and salinity intrusion has the potential to alter the upstream patterns and magnitude of instream flow releases that affect habitat quality and availability for salmonids and other fish species inhabiting rivers tributary to the Delta. Information from the hydrodynamics modeling and emergency response modeling will be used to develop indicators of environmental changes to habitat quality and availability within the major tributary rivers within the Central Valley. Information on the seasonal timing of changes in instream flows and the magnitude of flow changes will be used to assess potential upstream environmental effects associated with levee failure within the Delta. Indices of environmental changes to upstream habitats will be presented separately for each levee failure scenario investigated.

Species Selected for Analysis

A large number and variety of aquatic and terrestrial species inhabit the Delta and Suisun Marsh that would potentially be affected by one or more levee failures. As a consequence of constraints on available time and resources, and limitations on the data available for many of the species, the risk analysis could not be completed for all species. Furthermore, it is not necessary for the analysis to address every species. Rather, a set of species can be selected that represent the diversity of the ecosystem and which are relevant metrics for future decision making. Therefore, representative species were selected for inclusion in the framework for analysis. The species were selected after considering a number of factors that included, but were not limited to, the following:

- Is the species listed for protection under the California or Federal ESA and therefore has a higher risk of extinction in response to an environmental perturbation associated with a levee failure?
- Is the species vulnerable to population level impacts or possible extinction as a result of levee failure?
- Is the Delta or Suisun Marsh included within designated critical habitat for listed species or as essential fish habitat for managed species?
- Is the species identified as a sensitive species, species of concern, or identified for recovery within the estuary?
- Is the species an important prey item and/or major component in community biomass?
- Is the species life history representative of an assemblage of other species inhabiting the estuary?
- Is the species an important keystone species affecting habitat conditions or energy dynamics within the estuary?
- Is information available on habitat suitability in response to factors such as water temperature, salinity, water depth, and other environmental conditions that may change in response to one or more levee failures?
- Is the species identified for inclusion in the Delta Regional Ecosystem Restoration Implementation Plan (DRERIP)?

- Is the species representative of different life history characteristics and/or habitat uses within the Delta or Suisun Marsh (e.g., dependant on the estuary year-round to support different life stages, anadromous species that use the estuary as a migration corridor, etc.)?
- Is the species an important recreational or commercial resource?

Based on consideration of these general criteria aquatic and terrestrial species selected for inclusion in the for risk analysis framework include:

Selected Aquatic species

Delta smelt
Longfin smelt
Chinook salmon (all species)
Steelhead
Green sturgeon
Threadfin shad
Striped bass
Sacramento splittail
Egeria
Corbula
Corbicula
Predators (e.g., largemouth bass, pike minnow)
Primary and secondary production including macroinvertebrates

Selected Vegetation Communities/species assemblages

selection of species for inclusion in the analysis is underway

Selected Wildlife species

selection of species for inclusion in the analysis is underway

Level of Risk Analysis

The ability to develop quantitative and qualitative indicators of environmental effects in response to a levee failure is anticipated to vary among selected target species. The level of analysis and development of quantitative indicators for a selected species is influenced by a number of factors that include, but are not limited to, the following:

- The availability of information regarding habitat preference, tolerance to environmental conditions, and the biological response of a species and lifestage to changes in environmental conditions anticipated to occur in response to levee failure;
- The availability of information that can be used to support predictions of the biological response of individual organisms or populations to environmental perturbations;
- The sensitivity of a species or population to mortality or habitat displacement due to environmental disruption and the availability of information on species recovery;
- Limitations in the amount of time available to conduct the analyses; and
- The level of regulatory and societal interest in particular species (e.g., listed species under the California and/or Federal Endangered Species Act or species of concern), importance as a commercial or recreationally valuable resource, or importance as a keystone/indicator species in the estuarine ecosystem.

Decisions will be made regarding the level of analysis for each selected species based in part on results of the compilation and synthesis of available scientific information, and consultation with resource specialists and evaluation experts. Three general levels of analysis are proposed as part of the framework for individual species.

A **Level I** analysis (e.g., habitat suitability analyses and entrainment loss estimates) provides the highest level of detail, development of quantitative indices of the biological response of a species to each levee failure/island flooding scenario. The quantitative indices developed for these selected species are intended to estimate the potential magnitude of environmental impact/benefit resulting from levee failure. These indices will be developed based upon information on the species-specific and lifestage specific seasonal and geographic distribution within the estuary, habitat preference information, tolerances to environmental variability, life history, and population dynamics. Limitations in the availability of reliable information and time to conduct the analyses make conducting highly quantitative models for every species impossible. Instead, the team will focus the most intensive quantitative analysis on those species of the highest regulatory and societal importance, and for which sufficient data is available to generate biological relationships and to assess variability in response functions (e.g., confidence intervals, uncertainty). It is currently anticipated that Level I analyses will be developed for species such as delta smelt, Chinook salmon, and striped bass.

A **Level II** analysis provides the second highest level of detail, a qualitative analysis that will characterize responses of the species to each levee failure scenario. For this type of analysis, categories such as "lead to extinction"," large adverse effect", "small adverse effect", "relatively little effect", "small beneficial effects", and "large beneficial effects" will be used. The categories used will be related to the quantity and quality of information available, with relatively more specific categories used where more or better quality data is available, and relative broad categories used where little or poor quality data is available. For many species, information available from the scientific literature and/or resource experts is not expected to be robust or adequate to support quantitative analysis. For example, information on habitat preference for a given species or lifestage may be available from investigations conducted on other estuaries, such as Chesapeake Bay, that may or may not be representative of habitat preferences or biological response to a levee failure within the Delta and Suisun Marsh. For these species, information will be developed on predicted changes in environmental conditions in response to levee failures with the biological response of the target species limited to only an index of potential beneficial or adverse impacts. A Level II analysis would be selected for those species likely to be affected by levee failures, and where sufficient information is available to draw qualitative conclusions regarding the effects of changes in their habitats. It is currently anticipated that Level II analyses will be developed for species such as longfin smelt, steelhead, threadfin shad, Egeria, and Sacramento splittail.

A **Level III** analysis provides the lowest level of detail, general (not scenario-based) text describing the effects of levee failures/island flooding on species or habitats. For a number of the species information may not be available to support either a quantitative or a scenario-based qualitative analysis. Further, some species would be so unlikely to be affected by levee failures that a scenario-based analysis is not warranted. For these species and habitats, it is anticipated that a narrative text will be prepared based upon anticipated changes in environmental conditions for a limited number of levee failure scenarios representing a wide range of possible outcomes. For these species, the narrative discussion will be based on general information regarding their geographic distribution, life history, and habitat preferences, to the extent that information is available, and the use of generalized indicators of environmental change. Selective modeling results (particularly hydrodynamic/water quality modeling), covering a range of levee failure/island flooding events may also be used to describe the range of effects that could occur. It is currently anticipated that Level III analyses will be developed for species such as green sturgeon, Corbula, Corbicula, vulnerability to predation, and primary and secondary production.

Selected Levee Failure Scenarios

To test the performance of the analysis framework in developing environmental indicators that are representative of the conditions and response of a species experiencing a levee failure a range of three levee breach conditions have been selected for initial analysis. The three levee breach conditions include (1) a single breach on each of three islands, (2) multiple breaches on ten islands, and (3) multiple breaches on fifty islands. The three selected levee breach conditions are shown in Figures 18–20. The three levee breach conditions selected for use in testing the environmental analysis framework are intended to represent a wide range of potential environmental conditions within the estuary. Results of the initial test of the analytical framework, including the range of indicators developed for various species, will be compiled and presented to a selected group of resource and evaluation experts in a single day workshop format for their review and comment. Based on results of this initial test of the framework, modifications and refinements will be made to the biological response functions, assumptions, or analyses as needed to improve the performance and reliability of the approach for providing meaningful results on the potential environmental effects associated with levee failures. The revised framework and biological response functions, including estimates of uncertainty where appropriate, will be documented and provided by the environmental team for integration into the larger scenario-based levee failure risk assessment.

4.2 Uncertainty Characterization

Two fundamentally different sources of uncertainty exist that affect the results of the environmental risk analysis. These two types of uncertainty include:

- Aleatory Uncertainty - This first source is attributed to the inherent randomness of events in nature (e.g., a role of the dice, the occurrence of an earthquake or flood). It represents unique (often small-scale) details of material properties, the small-scale variability not explained by a ‘model’. Aleatory uncertainty cannot be reduced by collection of additional information. One may be able, however, to better quantify the aleatory uncertainty by using additional data. These events can only be predicted in terms of their probability or rate of occurring.

Epistemic Uncertainty - This second source of uncertainty is attributed to lack of knowledge (information, scientific understanding, data). For example, the ability to determine the rate of occurrence of an event requires that certain data be available. If the amount of data is adequate, the estimate of a rate may be quite accurate. On the other hand, if only limited data are available, the estimate of likelihood will be uncertain (i.e., statistical confidence intervals on parameter estimates will be large). Uncertainty is also attributed to our lack of understanding (e.g., knowledge) about a physical process or system that must be modeled. These sources of uncertainty are referred to as epistemic

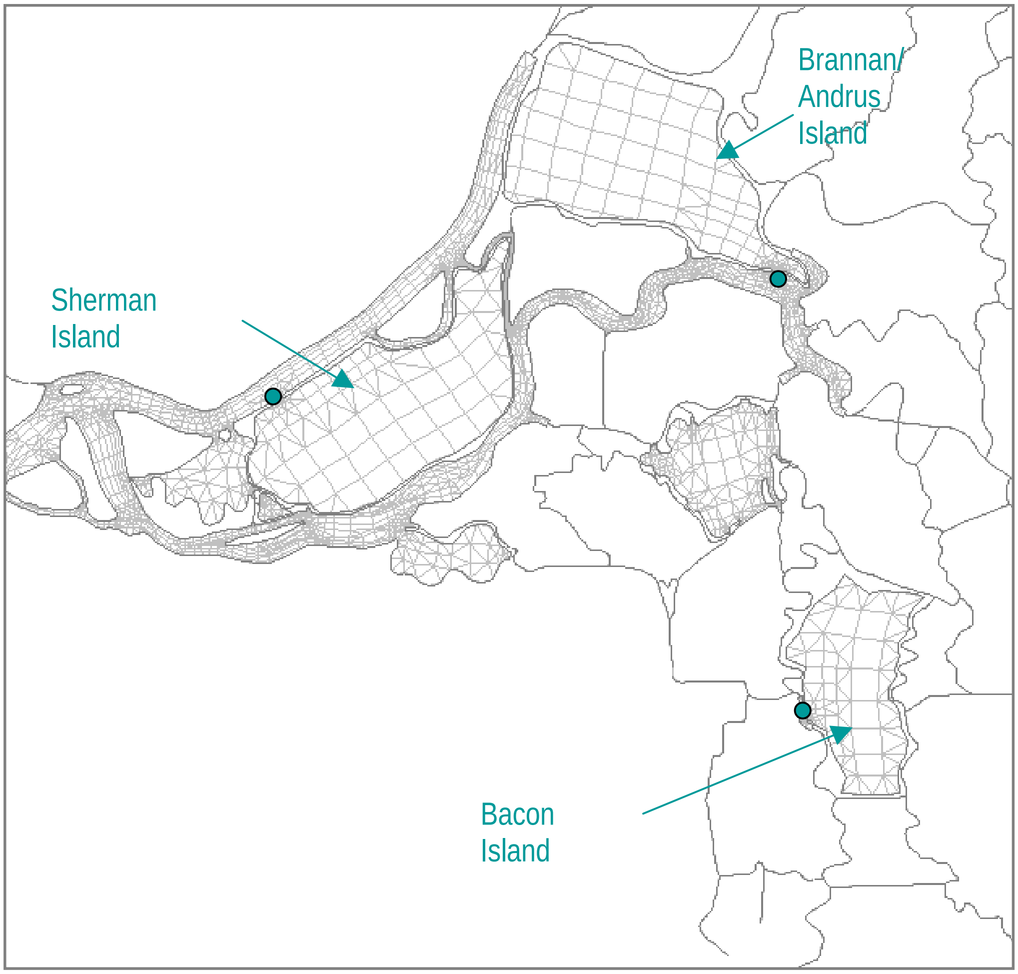

Figure 18: Example of a Three-Breach Levee Failure (RMA 2005).

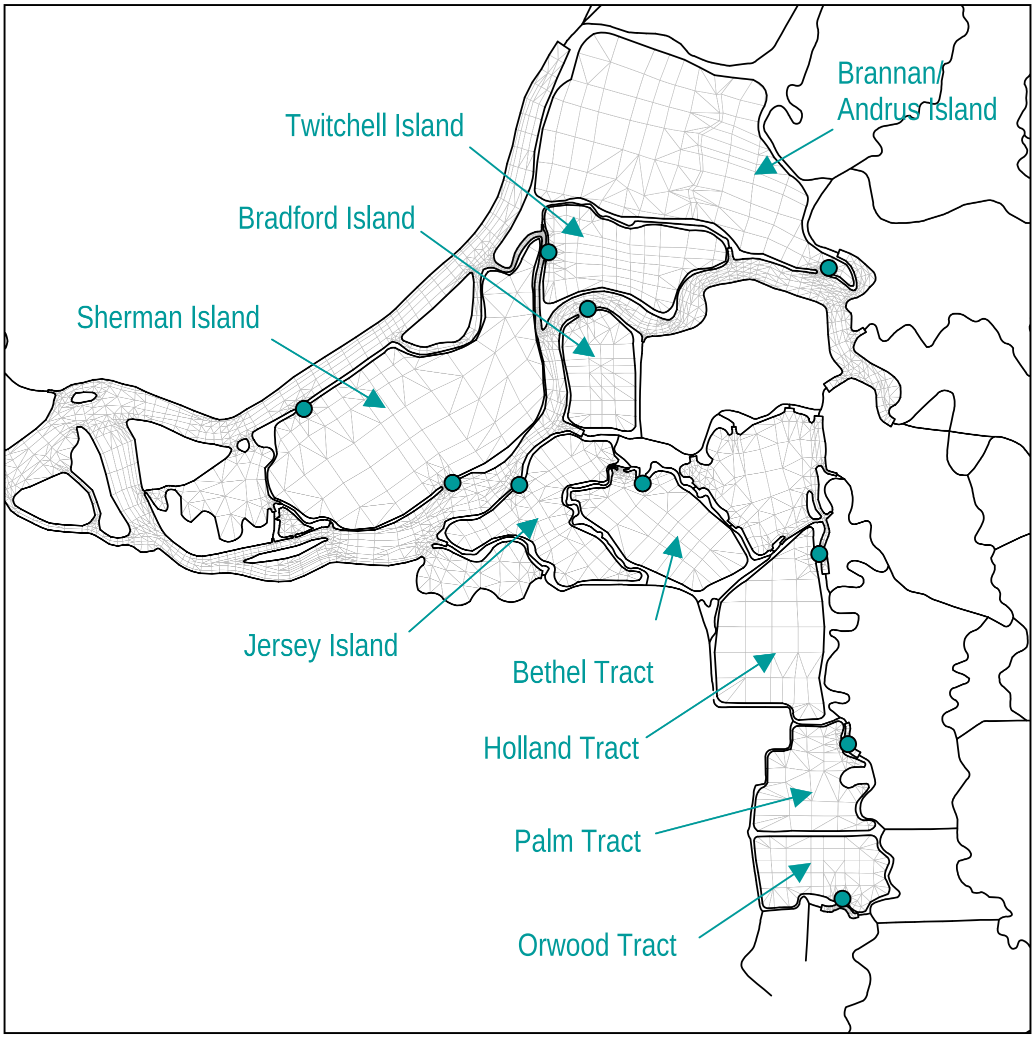

Figure 19: Example of a Ten-Breach Levee Failure (RMA 2005).

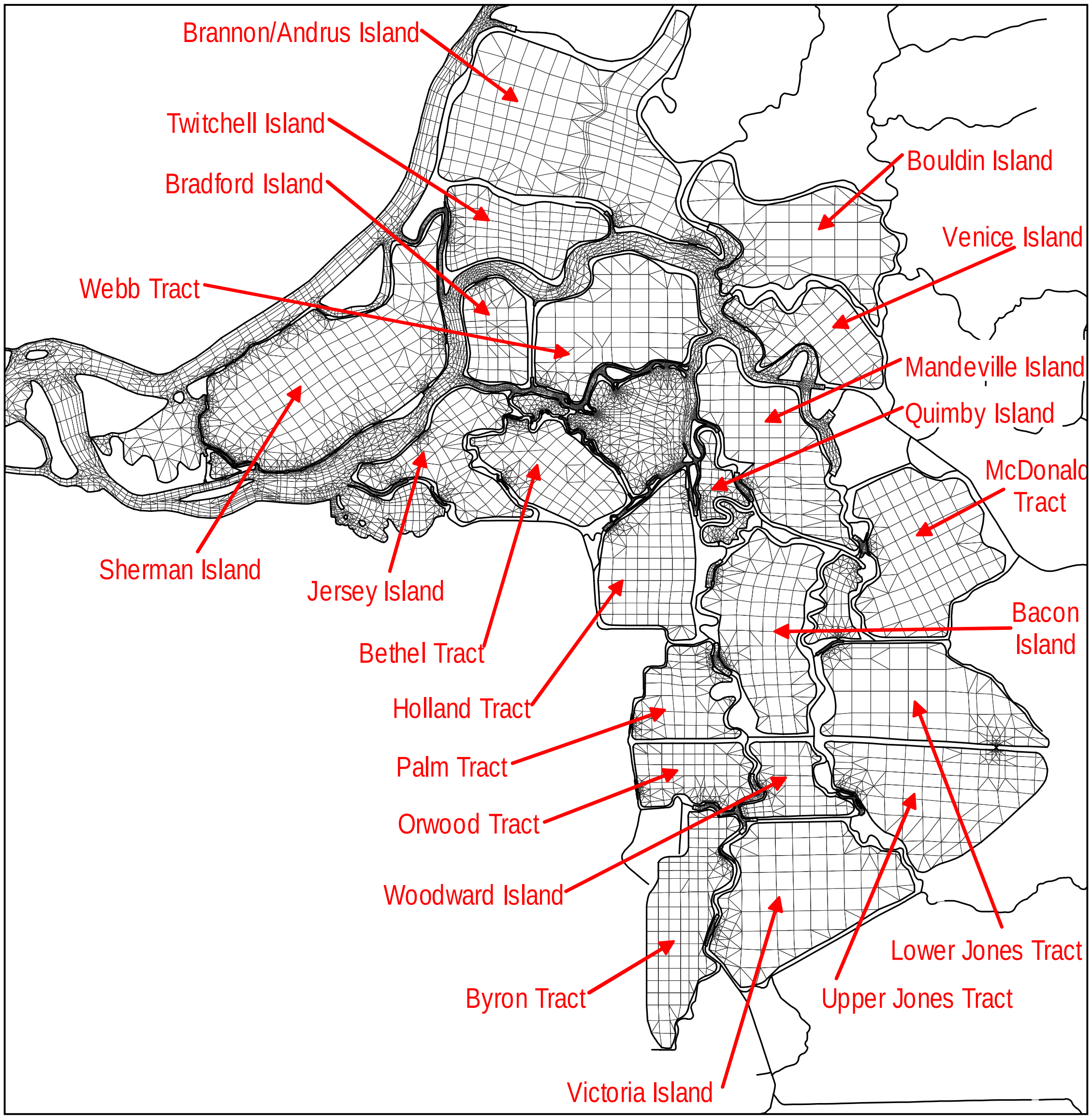

Figure 20: Example of a Fifty-Breach Levee Failure (RMA 2005).

(knowledge-based) uncertainty. In principle, epistemic uncertainty can be reduced with improved knowledge and/or the collection of additional information.

The identification and quantification of sources of epistemic uncertainty in each part of the DRMS risk analysis is an important part of the overall assessment. It will, for example, provide a measure of the uncertainty in the overall risk results and provide a basis for determining which uncertainties are most important to the overall risk results, and thus which areas require further study.

Approach to Evaluating Uncertainty

This subsection outlines the process for conducting the environmental effects analysis as it applies to the assessment of uncertainties (in particular epistemic uncertainty). The approach is based on the concepts and guidance described in SSHAC (1997), which builds upon the experience in the expert elicitation field and its application to earth science issues. Among other attributes of the SSHAC process and developments in the expert elicitation field, is the requirement to conduct expert elicitations in a formal, structured manner, whether experts are personally engaged or not (see discussion on the levels of expert elicitation). The need for formality in expert elicitation is motivated by the need for a process that deals with cognitive evaluation issues, scientific integrity of the evaluations and results, transparency, and defensibility. Objective of the Uncertainty Evaluation

An objective of the risk analysis and the assessment of epistemic uncertainties is to determine the composite distribution of predictions or anticipated biological responses to environmental parameters that may change in response to a levee failure based on the range of scientific responses to a variable presented in the scientific literature and inputs from the informed technical community (SSHAC 1997). This objective has important implications with respect to the environmental effects analysis and the DRMS risk analysis in general. First, it suggests, that if the composite distribution of the available scientific data and informed technical community has been evaluated and captured in the modeling and results, the results are extremely robust (scientifically sound within given confidence intervals) and defensible (credible scientific interpretations have been identified and considered.)

The objective suggests, at least figuratively, that the entire informed technical community must be involved in the evaluation. This of course is not practical, nor the intent. Rather the notion of the "informed technical community" is intended to capture the idea that in areas where there is considerable epistemic uncertainty and where there are alternative, credible and scientifically defensible interpretations of available data and biological response functions, the analysis must be conducted in a manner that identifies, evaluates, and represents the relative scientific range and credibility associated with these alternative interpretations. The environmental risk analysis framework and assumptions are designed to be transparent and allow the opportunity for identifying alternative hypotheses or interpretations of the available data and levee of uncertainty reflected in results of the levee failure analyses.

Different levels of analysis (approaches for carrying out the analysis) can be considered for use, while maintaining the objective expressed above. The selection of a level of analysis for a particular assessment depends on the resources available to conduct the evaluation, and the degree of complexity and importance of the problem. One such level involves direct involvement of a group of experts, but this is not the only approach, nor is it always necessary. In the environmental effects analysis it is anticipated that different levels of analysis will be used for different species (Section 4.1). In the next subsection, the types and roles of experts are discussed.

4.3 Types and Roles of Experts

Four categories of experts or expert groups are identified to participate in this study. The roles of these experts, which are discussed below, will vary, depending on the level of analysis that is used. The categories are:

- Methodology Team

- Resource Experts
- Evaluation Experts
- Risk Resource Group Members

A summary of the experts and their roles is provided in Table 1.

Levels of Expert Elicitation

Depending on the sensitivity and complexity of the scientific issues being evaluated, and the importance of the risk analysis results to decision making, there are three alternative levels of analysis for conducting expert elicitations (SSHAC 1997). For each level of evaluation, the objective is the same (as described in Section 4.2). Table 2 summarizes the alternative levels of expert elicitation.

Table 1
Summary of Types of Experts

Expert Type	Role
Methodology	The methodology team is composed of experts in the subject matter areas, probabilistic analysis, and uncertainty evaluation. The methodology team is responsible for all logistical and planning elements of the assessment and the preparation of the project report. The methodology team may also be responsible for (depending on the level of analysis as discussed in the next subsection): • Compile available data and scientific information • Review and evaluate the available data • Identify data gaps • Data analysis • Model quantification • Facilitation of expert evaluations • Integration of alternative models • Documentation
Resource	Resources experts are individuals who have gathered data, information, etc. that is essential to understanding the ecological impact issues, developing parameter estimates and/or empirical models, validating modeling approaches, etc. These experts have a unique understanding of the information that is available, insight as to data collection methods, completeness, sources of error, etc. These experts may also have insight into the results of data evaluation studies. As part of the environmental effects analysis, resources experts will be contacted and individually interviewed to identify and gather relevant data, etc.
Evaluation	Evaluation experts are individuals that have a unique technical and scientific understanding of the issues involved in the analysis and an ability to evaluate the spectrum of scientific hypotheses and interpretations which may exist. Depending on the level of analysis that is conducted (see the next subsection), evaluation experts may be engaged to discuss scientific issues associated with the modeling of environmental effects, identify alternative scientific interpretations, and provide insight to modeling approaches to the methodology team. Evaluation experts may be engaged to provide direct input to the risk analysis process, contribute to the model development, estimate model parameters and their uncertainty, and to evaluate the scientific merit of alternative models (see the next subsection)
Risk Resource Group	As part of the DRMS project, a group of technical experts was formed to serve as advisors to the risk analysis. Ecological experts are part of the risk resource group. The ecological and probabilistic modeling experts will be consulted by the Methodology Team and the DRMS technical management to provide advice and guidance on key areas such as environmental risk model development, information resources, etc. They may also serve in a review capacity.

Table 2
Levels of Analysis for Expert Elicitation

	Level		
Expert Type	**A**	**B**	**C**
	Highest Level Involvement	**Mid-Level Involvement**	**Lowest Level Involvement**
Methodology	Responsibilities include: • Data analysis • Model quantification • Facilitation of expert evaluations at project workshops and interviews. • Documentation of evaluation process, methodology and results. • Selection of evaluation experts; establish criteria for selection and participation.	Responsibilities include: • Data analysis • Model quantification • Facilitation of expert evaluations at a project workshop. • Technical integration of alternative models. • Documentation of evaluation process, methodology, basis for the evaluations and the study results. Methodology team has intellectual ownership of the model and results.	Responsibilities include: • Data analysis • Model quantification • Technical integration of alternative models • Documentation of evaluation process, methodology, basis for the evaluations and the study results. Methodology team has intellectual ownership of the model and results.
Resource	See description in Table 1. Experts may be asked to participate in project workshops.	See description in Table 1. Experts may be asked to participate in project workshops.	See description in Table 1.
Evaluation	Experts participate in project workshops, provide input to model development; develop model inputs and assess uncertainty; evaluate alternative models (assign probability weights to alternative models). Experts are required to present their evaluations to their peers (the other experts) and to document the basis for their evaluations. Evaluation experts have intellectual ownership of models and results.	Experts participate in a workshop to discuss/debate critical issues and contribute to understanding of the state-of-knowledge of the informed technical community and modeling alternatives.	Not directly involved; may be contacted by the methodology team for information and insight into modeling issues, most recent study results, etc.
Risk Resource	Oversight of elicitation process. Technical guidance and review.	Oversight of elicitation process. Technical guidance and review.	Technical guidance and review.

For all levels of analysis, in particular Level C in which evaluation experts are not directly engaged in the process, the technical and scientific literature as well as analysis of available monitoring data is used to identify and assess the state-of-knowledge of the informed technical community.

4.4 General Probabilistic Modeling Approach

One of the objectives of the environmental effects analysis is to develop and implement a probabilistic model (anticipated biological response of a species to a levee failure) that specifies (in quantitative or qualitative terms) the impact of environmental stressors that are the result of levee failures in the Delta and Suisun Marsh.

The basic template for the probabilistic models is illustrated in Figure 4. The environmental effects models must estimate the variation in the effect that different stressors initiated by levee failures may have on a species of its habitat (a risk metric). The probabilistic model development will be guided by the state-of-knowledge and the ability to discriminate the effects of variations in the stressors that can occur. For instance, while the assessment of the hydrodynamic response of the Delta and Suisun Marsh will provide a considerable level of detail with respect to salinity intrusion during a failure scenario, environmental assessment capabilities may only be able to broadly and qualitatively discriminate between the effects an event has on a particular species.

The probabilistic model for each risk metric will, to the extent possible based on the available scientific information, quantify the aleatory and epistemic uncertainty. For example, in Figure 21, the multiple bars of a given color model the aleatory uncertainty in the effect a given Delta state has for the risk metric being modeled. Alternatively, the second set of colored bars corresponds to an alternative estimate for the same Delta state that may be based on different interpretations or models. These two estimates would be assigned probability weights that reflect their scientific merit as evaluated by the informed technical community.

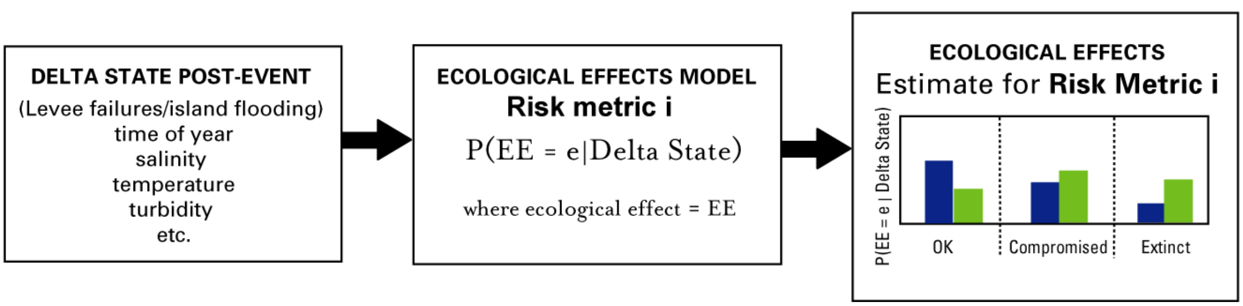

Figure 21: Schematic Illustration of the Paradigm for Environmental Effects Models.

4.5 Model Development and Evaluation

Model development will involve a series of steps that will vary depending on the level of analysis and involvement of evaluation experts. There are two basic elements to this part of the environmental effects analysis process. The first is the identification of the type of analysis (qualitative or quantitative) that can be implemented for a given risk metric. The process of the model development will consider:

- Identification of model issues, including key factors, alternative hypotheses, data availability, etc.;
- Independent levee failure scenario characteristics required to estimate environmental effects;
- Sources of aleatory and epistemic uncertainty;
- Opportunities for estimating model parameters and uncertainties;
- Model development; and,
- Parameter estimation and model validation (e.g., comparison to Jones Tract event outcomes).

As discussed in Section 4.1, performance of the initial formulation of the risk analysis will be tested against three levee failure scenarios. Results of the initial tests of the environmental effects indicators will be presented in a workshop format for review and comment. The model approach, assumptions, areas of uncertainty, and biologic response functions will subsequently be revised and refined prior to integration into the overall DRMS risk assessment framework.

5.0 INFORMATION REQUIREMENTS

The environmental effects analysis will use many sources of information. The primary sources of information will be data collected by the Interagency Ecological Program (IEP) and resource agencies regarding the seasonal and geographic distribution and relative abundance of selected aquatic and terrestrial of species within the Delta and Suisun Marsh. In particular, information collected seasonally on the species densities at a variety of locations in the Delta and Suisun Marsh will serve as the foundation for the analysis of fish (Figure 5). Information primarily from the California Natural Diversity Database (CNDDB) will provide information on the location of wildlife species populations, and recent vegetation surveys conducted by CDFG will provide information on the habitat types associated with each island within the Delta and Suisun Marsh. CDFG will be contacted to ensure that the most current data are available for use in the environmental risk analysis. The team is also reviewing information collected by agencies following the Jones Tract flooding event, as well as information from levee breaches (both managed and unmanaged) from within the Delta and elsewhere to determine the types of data on environmental conditions and biological responses that are available and helpful in building and validating the framework of assessing environmental risks and benefits of levee failure and island flooding.

In addition, biological and physical information about each island within the Delta and areas within Suisun Marsh is being compiled using GIS data, data collected by various resource agencies and other sources, and results of hydrodynamic and water quality modeling. Of particular importance are:

- The volume of each island when flooded;
- The maximum and average depth of each island when flooded;
- The acreage on each island in various water depth classes, when flooded;

- The volume of dirt entering the water column during each flood event to estimate turbidity effects;
- Sources of toxic substances on each island;
- Hydrodynamic characteristics of flooded islands and channels in the vicinity of a levee breach;
- Changes in the magnitude and geographic distribution of salinity in response to levee breaches;
- Changes in SWP and CVP export operations in response to levee breaches as a result of changes in salinity and other water quality constituents;
- Water current patterns within the channels adjacent to a levee breach that would affect fish migration patterns and potential vulnerability to increased predation mortality;
- Residence time and hydraulic dispersion from an island following a levee breach;
- The seasonal and geographic distribution of selected fish species within the Delta and Suisun Marsh and their densities;
- A vegetation map of the Suisun Marsh from the California Department of Fish and Game;
- A vegetation map of the Sacramento and San Joaquin Delta from the California Department of Fish and Game;
- The California Natural Diversity Database;
- Data or reports from the Jones Tract levee failure describing island use by wildlife before and following flooding, including recolonization following pumping. Also any assessment of direct and indirect effects on fish and wildlife, water quality, hydrodynamics, emergency response, etc.;
- Winter distribution and abundance of waterfowl, shorebirds, and sandhill cranes by island or subareas of the Delta and Suisun Marsh (e.g., mid-winter count data);
- Habitat distribution and occurrence maps for special-status species in the Delta and Suisun Marsh; and
- Information compiled from the scientific literature, technical reports, and available data sets on the habitat preferences, tolerance, and biological responses of the selected species to environmental conditions within the Delta and Suisun Marsh that may change as a result of levee failure.

6.0 MODEL INTEGRATION/LINKAGES/INTERFACES

The environmental risk analysis is based on information provided on environmental changes within the Delta and Suisun Marsh that would be expected to occur in response to levee failure. Information developed from complementary modeling elements of the project, such as the levee fragility modeling, hydrodynamic modeling, water quality modeling, and emergency response and repair all provide input that will be used in various aspects of the environmental analysis. Similarly, information developed from the environmental risk analysis will be provided as one factor in evaluating the potential economic effects associated with a levee failure scenario. Information developed through GIS analysis of current conditions within the Delta and Suisun Marsh will also be used as input to the environmental risk analysis. Examples of the model integration, information transfer, and linkages to the environmental risk analysis are presented below:

- Date of the levee breach (Levee Fragility);
- Length of the levee breach (Levee Fragility);
- Location of the levee breach (Levee Fragility);
- Occurrence of multiple levee breaches (Levee Fragility);
- Volume of water entrained onto the flooded island (GIS mapping);
- Changes in SWP and CVP export operations in response to levee failure (Hydrodynamics);
- Changes in upstream reservoir operations and instream releases (Hydrodynamics);
- Changes in on-island water diversions for irrigation (GIS mapping);
- Area of the island that is flooded (GIS mapping);
- Water depth within the flooded island (GIS mapping);
- Duration that the breach remains open (Emergency Response);
- Duration that the island remains flooded (Emergency Response);
- Changes in salinity for each scenario within the flooded island and adjacent channels (Hydrodynamics, Water Quality);
- Changes in water temperature, salinity, dissolved oxygen, and suspended sediments within and adjacent to each flooded island (Hydrodynamics, Water Quality);
- Changes in low salinity areas within the estuary (X2 location) and Suisun Marsh (Hydrodynamics, Water Quality);
- Changes in local water velocity patterns within the channels adjacent to a levee breach and within the flooded island (Hydrodynamics);
- Hydraulic residence time within a flooded island (Hydrodynamics);
- Particle entrainment onto the flooded island (Hydrodynamics); and
- Potential exposure to toxic contaminants within a flooded island (GIS mapping).
- Information developed through modeling and other analytical tools used to characterize changes in environmental conditions in response to a levee failure scenario will be integrated with information on the seasonal and geographic distribution of selected species developed from surveys conducted by CDFG, USFWS, UCD, and other investigators and the anticipated biological response of a species and lifestage to environmental conditions form the foundation for the environmental risk assessment.

7.0 ANTICIPATED OUTPUTS/PRODUCTS

The fundamental product of the environmental risk analysis will be a series of predictions of the response, both adverse and beneficial, of selected aquatic and terrestrial species to changes in environmental conditions resulting from levee failures in the Delta and Suisun Marsh. The risk assessment output will first focus on the predicted response to a series of three levee failure scenarios (three-breach, ten-breach, and fifty-breach scenarios) that will describe the predicted biological response in both quantitative terms (e.g., number of a given species entrained onto a flooded island, change in habitat suitability for a species, etc.; level I or II analysis) as well as a qualitative discussion of anticipated changes for species for which information on biological responses is limited and would not support quantitative analysis and for those processes such as the risk of particle entrainment onto a flooded island after the initial breach, changes in predation vulnerability or migration patterns, changes in primary production (phytoplankton, total organic carbon, etc.) and lower trophic levels (e.g., zooplankton, invasive clams, shrimp, crabs, etc.) that will not be quantitatively modeled (level III analysis).

In addition to the limited number of selected breach scenarios that will be examined in greater detail, probabilistic modeling will also be used to assess the anticipated response of selected aquatic and terrestrial species to a large number of modeled levee failure scenarios. This conditional risk assessment will incorporate both epistemic and aleatory uncertainty into model outputs to help provide insight into the degree of uncertainty in the predicted response of a species to levee failure. Managers and decision-makers will be able to evaluate the risks associated with various disturbance scenarios based on results of the environmental risk analysis and understand the strength of the predictions given the gaps in our knowledge base and limitations inherent in predicting environmental response to disturbance.

Results of the environmental risk analysis will be documented in a technical report that describes the framework for risk analysis, data used in the analysis, biological response relationships (e.g., habitat preference, tolerance to environmental conditions, etc.) for selected species, assumptions, and other information used in constructing the environmental risk analysis. The bases (published analyses, published and unpublished data, or best judgments of a community of experts) for all assessments included in the risk analysis will be documented. As part of developing the functional relationships associated with the species-specific models, the level of uncertainty in predicted outcomes will also be documented. This documentation will facilitate both (a) identification of key knowledge gaps that, if filled, will reduce model uncertainty, and (b) updates to the model as parameter/response estimates or their associated uncertainties change. The technical documentation report will present information on the selection of target species for analysis, limitations, constraints, and uncertainties in our current understanding of the biological response of a species or lifestage to changes in environmental conditions following a levee failure, and a discussion of both the quantitative and qualitative results of the three levee breach scenarios analyzed in detail, and the broader range of levee failure scenarios included in the larger set of conditional levee conditions.

8.0 PROJECT TASKS

This section identifies specific tasks, responsibilities, schedule, and milestones that will be used in developing the technical foundation for the environmental risk assessment. The tasks and schedule provide the basis for project management and the integration of the environmental risk assessment with other elements of the DRMS project.

8.1 Project Tasks

Develop Conceptual Models of Effect Mechanisms

As part of initial project planning, and with the help of the DRMS Technical Advisory Committee Ecosystem Group, a preliminary conceptual model of the mechanisms by which levee failures could affect selected aquatic and terrestrial species has been developed. The conceptual model has been used to identify the key parameters and functional relationships to be included in the environmental risk analysis such as:

- The seasonal timing of a levee failure related to the seasonal distribution of selected species and lifestages;
- The geographic location of a levee failure related to the geographic distribution of key species lifestages and key habitats;
- Changes in water depths within an area and the water depth preferences and requirements of key species lifestages and key habitats;
- Changes in salinity within an area and the salinity preferences and requirements of each key species lifestages and key habitats;
- Changes in hydrologic conditions within an area and the effect on habitat suitability for key species lifestages and key habitats;
- Changes in levels of turbidity and the preferences and requirements of key species;
- Changes in water diversion patterns and the effects on fish entrainment and fish salvage at water export facilities;
- The density of each key species lifestages within the area of a levee failure and the volume of water entrained onto a flooded island;
- The duration that the island remains flooded;
- The magnitude of levee breaching and the area of the Delta or Suisun Marsh where flooding occurs; and
- Exposure of key species lifestages and key habitats to toxic chemicals released during a levee failure event.

Select Target Species/Habitats

San Francisco Bay and the Delta estuary support 55 species of fish (Baxter 1999) and a substantially larger number of aquatic invertebrates, plants, birds, reptiles, amphibians, insects, and mammals. Given the complexity and scope of the analysis to be undertaken, practicality demands that a much smaller list of key species and habitats be selected to represent effects on the ecosystem as a whole. The general criteria and species selected for risk analysis are presented in Section 4.1.

Develop Biological Response Relationships

Information available from the scientific literature and from surveys conducted within the Delta and Suisun Marsh will be compiled for selected species. This information will be used to characterize habitat preference and tolerance to environmental parameters such as water depth, salinity, and water temperature. Based on the life history and habitat use within the estuary biological response relationships will be developed for different lifestages of a species (those inhabiting the Delta or Suisun Marsh). Information has also been compiled from surveys conducted by CDFG and others on the seasonal and geographic distribution of selected aquatic and terrestrial species that will be used in combination with information from the levee failure modeling on the seasonal timing and location of failures as part of the basis for the risk analysis.

8.2 Level of Analysis

The level of risk analysis that will be performed for different selected species will vary depending on the availability of information describing the anticipated biological response to changes in environmental conditions during and after a levee failure. For some species, such as juvenile Chinook salmon, there is a substantial body of scientific information on habitat preferences, tolerance to various environmental parameters, and the predicted response to levee failure. For these species, sufficient data may be available to generate statistical relationships (e.g., linear and non-linear regression models) that can also be used to assess variability in response functions (e.g., confidence intervals).

For other species, data on responses to the types of environmental changes that may occur due to levee failures is not available or has a high degree of uncertainty associated with it. For these species, the functional relationships may be developed based on a combination of data and professional judgment among the resource specialists and evaluation experts.

For some species the constraints on available data and other factors is expected to limit the risk analysis to a qualitative discussion of the anticipated changes with little or no quantification of the predicted outcome of a levee failure on these species.

8.3 Model Development and Evaluation

In this step, the actual relationships between the dependent and independent variables are defined. For each of the biological response functions included in the analysis information on the level of uncertainty will be integrated into the risk analysis and reflected in each levee failure condition analyzed. A large amount of uncertainty will be associated with this analysis. Uncertainty is associated with interpretation of existing data for a species, the range of individual responses and tolerances, variations in habitat preferences, and other factors related to developing a single response curve that is representative of the species. Other sources of uncertainty include lack of data regarding:

- The manner in which individual effects on species lifestages compound or interact to produce overall changes in individuals;
- The manner in which changes in individuals lead to changes in population levels of the species;
- The manner in which changes in individual species lead to changes in ecosystem-level effects; and
- How the ecosystem will change and what baseline conditions will be like 50, 100, or 200 years in the future.

In part, the biological significance of a levee failure on a specific species is dependant on the cumulative contribution of a variety of factors that are independent of levee failures. For example, additional introductions of exotic species and associated changes in the Delta trophic structure may alter the resiliency of a species to recover from the impacts of a levee failure. We have very limited ability to predict what new introductions may occur, and their effects. Further, even for factors being addressed within the risk analysis (changes in land use patterns, hydrology, project operations, sea level rise), little information is available to allow prediction of the effects on species or the ecosystem. Many of the uncertainties affecting both current and future conditions within the Delta and Suisun Marsh will be identified and discussed as part of the assessment however quantification of the uncertainties for many of these relationships, particularly those involving ecosystem changes, population level consequences, and future conditions with confidence will not be possible. Consultation with resource and evaluation experts will be used to help identify the most appropriate and scientifically valid methods for describing uncertainty within the various relationships and predictions of the environmental risk analysis.

To test and validate the environmental risk analysis framework three levee failure scenarios have been selected for the initial investigation of the risk analysis approach. The three failure scenarios include a three-breach condition (Figure 18), a ten-breach condition (Figure 19), and a fifty-beach condition (Figure 20). Information on the physical characteristics of each of these three failure scenarios has been developed along with predicted information on the changes in water quality (e.g., salinity) and other inputs from the hydrodynamics and water quality models to test the biological response functions. Predicted biological responses for each of the selected species for each of the breach scenarios will be developed using the framework for the risk analysis. Results of the analysis will be presented to a group of resource and evaluation experts in a workshop format for review and comment. Based on the review comments the risk analysis framework will be refined and subsequently integrated into the larger levee failure modeling framework.

8.4 Evaluate Risk Model Results

Results of the environmental risk analysis will be presented as a number of independent indicators of predicted changes for a given species in combination with information on the range of uncertainty in the predicted response. For some of the indicators the predicted response to a levee failure will be environmental enhancement and an improvement in habitat relative to baseline conditions. For other indicators it is anticipated that levee failure will result in adverse impacts to a species. Indicators of predicted responses will be presented separately for each species and levee failure scenario tested. Consideration will be given to developing composite indicators of environmental effects of levee failure conditions.

8.5 Technical Documentation Report

The environmental risk analysis framework, assumptions, biological response relationships, and results and interpretation of levee failure scenarios on the selected aquatic and terrestrial species will be documented in a technical report. The technical report will include information on the scientific literature and analysis of data used to derive the biological response relationships and the uncertainty associated with the available information. The report will present results of both the quantitative and qualitative environmental risk analysis. The draft documentation report will be provided for review and comment. Based on the review comments the draft report will be revised and finalized.

9.0 LITERATURE CITED

Baxter, R.D. 1999. Osmeridae. In: James Orsi, editor. Report on the 1980-1995 fish, shrimp, and crab sampling in the San Francisco estuary, California. Pages 179-215 Interagency Ecological Program Technical Report 63.

Carlton J.T. 1979. Introduced invertebrates of San Francisco Bay. Pages 427-444 *In:* San Francisco Bay - The Urbanized Estuary. T.J. Conomos (ed). Am. Assoc. Adv. Sci., Pacific Division, San Francisco.

CDFG (California Department of Fish and Game). 1964. The effect of water development on the Delta environment. Annual report (1963-1964). Delta Fish and Wildlife Protection Study. *Cited In*: Ecological Analysts, Inc. Pittsburg Power Plant Cooling Water Intake Structures 316(b) Demonstration. 1981.

Cohen, A. N. 1998. Ships' Ballast Water and the Introduction of Exotic Organisms into the San Francisco Estuary: Current Status of the Problem and Options for Management. San Francisco Estuary Institute, Richmond CA.

DWR (California Department of Water Resources). 2002. Source: http://iep.water.ca.gov/suisun/map/index.html.

Ecological Analysts, Inc. 1981. Pittsburg Power Plant Cooling Water Intake Structures 316(b) Demonstration. Prepared for: Pacific Gas & Electric Company (PG&E).

Kotra, J.P., M.P. Lee, and N.A. Eisenburg. 1996. Branch Technical Position on the Use of Expert Elicitation in the High-level Radioactive Waste Program. U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards, Division of Waste Management; NUREG-1563. Washington D.C.

May, R.M. 1974. Biological populations with non-overlapping generations: stable points, stable cycles, and chaos. Science 186:645-47.

RMA Water Resources Engineering. 2005.

Rosenfield, J.R. 2002. Pattern and process in the geographical ranges of freshwater fishes. Global Ecology & Biogeography 11:323–332

SSHAC (Senior Seismic Hazard Analysis Committee). 1997. Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts, NUREG/ CR- 6372.

Stephens, P.A., and W.J. Sutherland. 1999. Consequences of the Allee effect for behaviour, ecology, and conservation. Trends in Ecology and Evolution 14:401-405.